Thoracic dysfunction in whiplash associated disorders: A systematic review

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Abstract

Background
Research investigating Whiplash Associated Disorder (WAD) has largely focused on the cervical spine yet symptoms can be widespread. Thoracic spine pain prevalence is reported ~66%; perhaps unsurprising given the forceful stretch/eccentric loading of posterior structures of the spine, and the thoracic spine’s contribution to neck mobility/function. Approximately 50% WAD patients develop chronic pain and disability resulting in high levels of societal and healthcare costs. It is time to look beyond the cervical spine to fully understand anatomical dysfunction in WAD and provide new directions for clinical practice and research.

Purpose
To evaluate the scope and nature of dysfunction in the thoracic region in patients with WAD.

Methods
A systematic review and data synthesis was conducted according to a pre-defined, registered (PROSPERO, CRD42015026983) and published protocol. All forms of observational study were included. A sensitive topic-based search strategy was designed from inception to 1/06/16. Databases, grey literature and registers were searched using a study population terms and key words derived from scoping search. Two reviewers independently searched information sources, assessed studies for inclusion, extracted data and assessed risk of bias. A third reviewer checked for consistency and clarity. Extracted data included summary data: sample size and characteristics, outcomes, and timescales to reflect disorder state. Risk of bias was assessed using the Newcastle-Ottawa Scale. Data were tabulated to allow enabling a semi-qualitative comparison and grouped by outcome across studies. Strength of the overall body of evidence was assessed using a modified GRADE.

Results
Thirty eight studies (n>50,000) which were conducted across a range of countries were included. Few authors responded to requests for further data (5 of 9 contacted). Results
were reported in the context of overall quality and were presented for measures of pain or dysfunction and presented, where possible, according to WAD severity and time point post injury. Key findings include: 1) high prevalence of thoracic pain (>60%); higher for those with more severe presentations and in the acute stage, 2) low prevalence of chest pain (<22%), 3) evidence of thoracic outlet syndrome, with some association to and involvement of the brachial plexus, 4) muscle dysfunction in the form of heightened activity of the sternocleidomastoid or delayed onset of action of the serratus anterior, 5) high prevalence of myofascial pain and trigger points in the scalene muscles, sternocleidomastoid and mid/lower fibres of trapezius muscle (48–65%), and 6) inconclusive evidence of altered thoracic posture or mobility.

Conclusions

Considerable evidence supports thoracic pain and dysfunction in patients with WAD, involving primarily nerves and muscles. Notwithstanding the low/very low level of evidence from this review, our findings do support a more extensive clinical evaluation of patients presenting with WAD. Additional high quality research is required to further characterise dysfunction across other structures in the thoracic region, including but not limited to the thoracic spine (mobility and posture) and thoracic muscles (stiffness, activation patterns). In turn this may inform the design of clinical trials targeting such dysfunction.

Introduction

The cumulative incidence of patients seeking healthcare post-whiplash from a road traffic accident has increased over the last 30 years to an annual incidence of between 3 and 6/1000 inhabitants in North America and Western Europe [1]. Following injury, individuals experience a range of clinical manifestations, described as Whiplash Associated Disorder (WAD), including neck pain, fatigue, nausea, low self-reported physical and mental health, cognitive impairments and pain in multiple sites [2]. The severity of presentation in WAD is categorised according to the Quebec Task Force Classification (QTF) where the presence of clinical signs and symptoms relate to the severity of the disorder [3].

Whilst research has identified risk factors for poor prognosis [4, 5], and enhanced understanding of neurophysiological changes [6], it is not known why disability and pain persist beyond normal tissue healing times. With 40–60% patients progressing to experience chronic whiplash associated disorder (CWAD), estimated costs of ~$4 billion (USA) and ~€10 billion (Europe) associated with management and time off work [7, 8], further research is needed to fully understand anatomical dysfunction in WAD and provide new directions for clinical practice and research. This includes the effects on anatomically related body regions, such as the thoracic spine. Potential ongoing dysfunction in the thoracic region may partially explain why there is inconclusive evidence for the effectiveness of physiotherapy management for WAD II, where interventions target a primary complaint of neck pain [9, 10].

Although current research into WAD has focused on the primary complaint of neck pain [11], symptoms may also include stiffness [12, 13] and pain in other regions including the jaw, head, upper and lower limbs, chest, abdomen and groin [14]. Moreover, data from a large cohort study (n = 6481) reported that 66% of individuals complained of thoracic mid-spine pain post whiplash injury, with 23% still experiencing symptoms one year later [14]. This is
not surprising given the mechanism of a whiplash injury which involves forceful stretch loading to the upper back muscles; muscles which span both the neck and thoracic spine [15]. Recent evidence supports the presence of pathology in the mid/lower fibres of the trapezius muscle where they insert onto bone (myofascial-entheseal dysfunction) [16], which may partly account for the high prevalence of thoracic pain reported in both acute (65.5%) [14] and >80% in chronic WAD [17]. Furthermore, a number of abnormalities have been documented for the trapezius muscle in people with chronic WAD including histological changes as well as changes in muscle behaviour [18, 19].

With reduced cervical mobility being characteristic of chronic WAD and evidence that the thoracic spine contributes up to 33% and 21% of the movement occurring during neck flexion and rotation respectively [20] perhaps thoracic mobility is impaired following a whiplash injury; however at this time relatively little is known about the impact of WAD on this spinal region [21]. Research is now needed to examine the impact of injury on the thoracic spine in WAD.

Nevertheless, a systematic review of the current evidence has never been conducted to examine the scope and nature of dysfunction/impairment in the thoracic spine region following whiplash injury and in WAD. Knowledge of such dysfunction may be used to inform clinical practice and examination of patients with WAD, but also future clinical trials of novel interventions targeting thoracic impairments in WAD.

**Objectives**

The primary objective is to evaluate the scope and nature of dysfunction in the thoracic spine region in patients with WAD. A secondary objective is to explore the scope and nature of such changes based on severity using the Quebec Task Force classification (I-III) and stage post injury (acute/sub-acute less than 3 months or chronic 3+ months). Thirdly, we wish to make evidence based recommendations for clinical practice and future research.

**Methods/Design**

**Protocol and registration**

A systematic review of all forms of observational study was conducted according to a pre-defined protocol [22], in line with the Centre of Research and Dissemination Guidelines [23], Meta-analyses of Observational Studies in Epidemiology (MOOSE) [24] and is reported in line with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [25], S1 Table. PROSPERO (Registration number: CRD42015026983).

**Eligibility criteria**

Eligibility criteria informed using SPIDER [26], included that the sample (S) comprised patients aged >19 years; the phenomenon of interest (PI) was a WAD following motor vehicle or sporting injury; investigated using an observational study design (cohort, case control, single case study) (D) with evaluation of patient reported or performance based measure(s) of thoracic dysfunction of one or more of the following: muscle with an insertion to the thoracic cage, bone or joint of the thoracic cage, neural tissue related to the thorax (E).

Exclusion criteria included: studies investigating upper trapezius, studies investigating a central pain mechanism or neurophysiology of pain where no testing took place in the thoracic region, simulation or modelling studies, fractures (WAD IV), visceral injury or fibromyalgia.
**Information sources**

The search employed sensitive topic-based strategies designed for each database from inception to 1/6/16. No language or geographical restrictions were included. Databases included, CINAHL, EMBASE, MEDLINE, ZETO C, Index to Chiropractic Literature ChiroAccess and Google Scholar. Selected Internet sites and Indexes including, Turning Research into Practice, PubMed, National Research Register and Cochrane Back Review Group were also searched. Hand searching of key journals included Spine and the European Spine Journal. Grey literature included British National Bibliography for Report Literature, Dissertation Abstracts, Index to Scientific and Technical Proceedings, National Technical Information Service and the System for Information on Grey Literature.

**Search strategy**

The search strategy included terms related to whiplash associated disorder and patient reported or performance based measures of thoracic dysfunction. Terms and keywords derived from the scoping search and experts [subject specific (NRH,AR) and methodological (NRH,AR)] included: ‘whiplash’, ‘whiplash associated disorder’, ‘WAD’, ‘whiplash injury’, ‘motor vehicle accident OR collision’, ‘road traffic accident’, ‘cervical strain’ and ‘thoracic spine’, ‘dorsal spine’, ‘mid-spine’, ‘thoracic injuries’, limiting to adults >19 years and diagnosis to achieve the best balance of sensitivity and specificity. An example a search from Medline is included S2 Table. Terms were adapted to reflect spelling differences and [14] unique searching features of individual databases. Reference lists of included papers were also searched.

**Study selection**

Two reviewers (NRH, RS) independently searched information sources and assessed identified studies for inclusion, facilitated by grading each eligibility criterion as eligible/not eligible/might be eligible [27]. Full texts were reviewed and included when both reviewers agreed [23]. A third reviewer (IT) mediated in the event of disagreement [28].

**Data collection process and items**

Using a standardised form, the two reviewers extracted data independently [23]. A further reviewer (IT) independently examined data for accuracy and clarity. Authors were contacted for additional information or data where required.

**Data items**

Data were extracted from each study, including: study design, sample characteristics including age, gender, severity of WAD using the QTF Classification if reported, time point post injury and patient reported or performance based measures of thoracic dysfunction.

**Risk of bias in individual studies**

Risk of bias for each included study was independently assessed by the same initial reviewers. The third reviewer mediated in situations of disagreement. All tools and processes were piloted prior to use. Risk of bias was only assessed for cohort and case-control studies using the Newcastle-Ottawa Scale [29]; that includes eight items that are rated and categorised into three groups, namely selection, comparability and outcome.
Summary measures

Summary measures of patient reported or performance based measures of thoracic dysfunction are presented in the form of prevalence data and confidence intervals where provided, for thoracic pain, chest pain, thoracic outlet syndrome (TOS), myofascial pain and trigger points, dysfunction involving the brachial plexus, thoracic spine posture or mobility. Results are presented where possible, according to severity (QTF) and stage of WAD i.e. acute/sub-acute (< 3 months) or chronic (> 3 months).

Synthesis of results

In accordance with the protocol [22] meta-analyses would be performed where a sufficient number of studies share all of the stated characteristics; design, measure of dysfunction, severity based on QTF and stage post whiplash injury.

Quality of evidence across studies

Quality of evidence, including risk of bias across studies was evaluated using GRADE [30] for individual outcomes of interest. By their very nature, observational studies are considered 'low quality' although could be upgraded where a large dose response was evident, or the effects could not be accounted for by bias [30]. Likewise, findings could be downgraded to 'very low' where concerns were identified from the body of studies relating to precision, consistency, directness, precision or potentially other additional domains relating to strength of association e.g. magnitude of effect [30].

Results

Study selection

A total of 38 studies met the eligibility criteria, including 19 cohort studies, 16 case control studies and 3 single case studies/reports. The process of selection is detailed in Fig 1, with the list of excluded studies and reasons provided S3 Table.

Study characteristics

Study characteristics are detailed in Table 1. A range of measures of thoracic dysfunction were identified, including thoracic pain, chest pain, involvement of the brachial plexus, thoracic outlet syndrome, changes in muscle activation etc. An overview of the types of dysfunction is provided in Table 2 and, where possible, is presented according to severity and stage following injury.

Risk of bias within studies

Agreement of risk of bias following discussion was excellent with studies ranging considerably in quality from 1/9 to 7/9. Key methodological flaws included poor definition of cases, representativeness of cases, lack of non-exposed cohort, lack of blinding, controlling for risk factors beyond age and gender and clarity of follow up time point in cohort studies. There were many instances where information was missing and email requests for additional data or clarification was unforthcoming, resulting in ratings being ‘unclear’. See Table 3 for risk of bias for cohort studies and Table 4 for case control studies.
Results of individual studies

From this review we identified evidence of the following dysfunction: thoracic spine pain in acute/sub-acute/chronic WAD ranging from minor injuries to more severe (WADIII) presentations [11, 14, 17, 32, 33, 43, 50, 52, 58, 62]; chest pain in acute/sub-acute/chronic WAD [11, 17, 52, 53]; postural changes [44, 61] and reduced chest/thoracic mobility in CWAD [61]; thoracic outlet syndrome in CWAD [31, 35, 36, 47, 51]; involvement of the brachial plexus at all stages and across all levels of WAD severity [12, 46, 55, 57, 59]; muscle dysfunction in the form of the following: 1) heightened activity of the sternocleidomastoid during neck flexion [12, 56], 2) delayed onset of serratus anterior during arm elevation at the chronic stage in mild WAD [45] and 3) a high prevalence of myofascial pain and trigger points in the scalene muscles [40, 41], sternocleidomastoid [37, 40, 41] and mid/lower fibres of trapezius [16] within the sub-acute and chronic stages and across different levels of severity.

Synthesis of results

Synthesis of findings from cohort and case control studies across outcomes of dysfunction are provided in Tables 5–8. Sub-grouping according to stages and defined populations are included where reported. A summary of overall quality is provided based on GRADE following appraisal of risk of bias, consistency, precision, directness and effect size. Clinical heterogeneity across samples with respect to severity of presentation, time post injury and outcomes precluded meta-analysis being performed. Few studies stated a primary aim which accurately reflected the aims and objectives of this review.

Thoracic spine pain. Despite the very low quality of included studies, there is evidence of thoracic spine pain in a sub-acute WAD population (n = 11,576) [11, 14, 17, 34, 39, 43, 52, 60], with prevalence ranging between 21%-66%. Findings were inconsistent in chronic WAD, with prevalence ranging 0–94% [17, 50]. Study quality, differing time points post injury, differing measurement approaches and higher degrees of WAD severity could partly account for the inconsistency. For example, chronic WAD, studies with less severe presentations (minor or WADII) [32, 50] demonstrated lower prevalence rates (0–15.3%) compared to studies investigating WADII/III where prevalence was 54% [58]. Just one study reporting thoracic pain.
| Author & Date | Design | Sample | Age | Gender | WAD patients | Findings | Assessment | Findings |
|--------------|--------|--------|-----|--------|--------------|----------|------------|----------|
| Alexandre 2005[31] | Cohort | Minor WAD (including n = 1 severe, n = 4 moderate) | Chronic: 7 years + | Male 60% | WAD II (n = 25) | Thoracic outlet syndrome due to brachial plexus entrapment | Clinical examination • Electrodiagnostic testing |
| Berglund 2001[32] | Case control | Minor WAD (including n = 1 severe, n = 4 moderate) | Chronic: 7 years + | Male 50% | WAD II (n = 25) | Thoracic pain prevalence post rear end collision | Postal questionnaire • Thoracic pain prevalence post rear end collision (%, 95% CI, and number) |
| Bismil 2012[16] | Cohort | Chronic WAD II (>6 mths) | For subgroup: mean age 42 years | Female 60% | WAD II (n = 25) | Myofascial-entheseal dysfunction | Clinical examination |
| Bock 2005[33] | Cohort | Chronic WAD (>3 mths) | Mean, range (SD) age 40.9, 16–72 (14.8) years | Female 56% | WAD II (n = 25) | Thoracic outlet syndrome | Clinical examination |
| Bodack 1998[34] | Case report | Acute WAD (n = 1) | Female | WAD (n = 1) | Upper back pain | Clinical examination |
| Bortsov 2014[11] | Cohort | Age tertiles at baseline | • 18–26 years n = 315 | Male 57% | WAD II (n = 25) | Thoracic and chest pain | Clinical examination |
| Author & Date       | Design                                   | WAD patients                        | Age Gender | Sample | Assessment                                         | Findings                                                                 |
|---------------------|------------------------------------------|-------------------------------------|------------|--------|---------------------------------------------------|--------------------------------------------------------------------------|
| Cornips 2014 [39]   | Case series of surgical cases for TDH    | Chronic WAD                         | Range age 26–58  
• Females n = 7  
• Males n = 3 | N = 10  
(N = 4 had ‘typical whiplash based on MOI & complaints) | Clinical examination and imaging (from 326 discectomies for ≥ 1 thoracic disc herniation) | Thoracic pain (local) with thoracic disc herniation  
N = 10, ranging from significant axial pain to paretic-paralytic (significant motor weakness)  
• Significant axial and thoracic radicular pain n = 1  
• Significant axial and lower leg pain with or without thoracic radicular pain n = 3 |
| Ettlin 2008 [40]    | Case control                             | Chronic WAD (with or without neurological deficit were included) | Mean (SD) age 38.57  
(10.18) years  
Females n = 35 (74.5%) | WAD N = 47 | Clinical examination | Myofascial trigger points scaleneus medius and SCM  
Prevalence (%)  
WAD  
• Scaleneus medius 30 (63.8)  
• SCM 24 (51.1)  
Control  
• Scaleneus medius 3 (12.5)  
• SCM 3 (12.5) |
| Fernandez-Perez 2012 [41] | Case control                              | Sub-acute WADII (states acute in text) Within 1 month | Mean (SD) age 28.7  
(12.4) years | WAD N = 20 | Clinical examination | Myofascial trigger points (scaleneus medius and SCM)  
Number of participants with MTP  
WAD  
• Scalene Active R 6, L4, Latent R 9, L10, No R 5, L6  
• SCM Active R1, L6, Latent R12, L9, No R7, L5  
Control  
• Scalene Active R0, L0, Latent R2, L4, No R18, L16  
• SCM Active R0, L0, Latent R4, L5, No R 6, L35 |
| Ferrari 2010 [42]   | Cohort                                   | WADI & II (acute, sub-acute) Presented at 7 days. FU at 3 months | Mean, range (SD) age 37.5, 18–71 (13) years  
• Female n = 37  
• Male n = 32 | N = 69 | Clinical examination | Brachial plexus provocation test (Pain and elbow ROM)  
3 months:  
• VAS: mean (SD)2.2 (1.2)  
• Elbow extension: 41.5 (23) degrees  
Expectation predicted elbow angle and VAS on BPPT at 3 months  
Significantly smaller angle when expected to ‘get better slowly’ or ‘get better soon’ vs the other 2 categories VAS for ‘get better soon’ 1 point less than other 3 groups |
| Hartling 2002 [43]  | Cohort                                   | WADI-III <2 weeks and 6 mths         | No details  | N = 380 | Clinical examination | Upper back pain  
<2 weeks: 74.6% adjusted OR 2.91  
(1.65, 5.12)  
Symptoms intensity OR (95% CI)  
• Mild 3.09 (1.50, 6.38)  
• Moderate 4.17 (2.08, 8.36)  
• Severe 15.63 (6.07, 41.51)  
Symptoms frequency OR (95% CI)  
• Mild 3.47 (1.25, 9.66)  
• Moderate 5.36 (2.84, 10.17)  
• Severe 5.30 (2.53, 11.18) |
| Author & Date          | Design          | WAD patients                        | Age                      | Sample | Assessment   | Findings                                                                 |
|-----------------------|-----------------|-------------------------------------|--------------------------|--------|--------------|--------------------------------------------------------------------------|
| Helgadottir2011a [44] | Case control    | Chronic WADII (> 6 months)          | WADII Mean (SD) age 33.37 (9.58) years NDI 38 (18.74) Female n = 20 Male n = 3 | WAD N = 23 | Clinical examination | In WAD group: No difference was found in the mid thoracic curve ($p = .99$) |
|                       |                 |                                     |                          |        |              |                                                                           |
|                       |                 | Control Mean (SD) 29.70 (7.75) years Female n = 17 Male n = 3 | Control N = 20           |        |              |                                                                           |
| Helgadottir2011b [45] | Case control    | Chronic WADII (> 6 months)          | WADII Mean (SD) age 33 (10) years VAS 6(2) NDI 38 (18) Female n = 24 Male n = 3 | WAD N = 27 | Electromyography | Muscle activation and duration (middle trapezius, lower trapezius and serratus anterior) |
|                       |                 |                                     |                          |        |              | Delayed onset of serratus anterior muscle activation in the WAD group ($p < .01$) |
|                       |                 |                                     |                          |        |              | Reduced duration of muscle activity in the WAD group ($p < .01$)          |
|                       |                 |                                     |                          |        |              | No change in in middle and lower trapezius                              |
|                       |                 | Control Mean (SD) 30 (8) years Female n = 18 Male n = 5 | Control N = 23           |        |              |                                                                           |
| Hincapie2010 [14]     | Cohort          | WAD < 30 days post traffic injury   | Mean (SD) age 37.2 (15.2) years Female 60.2% Male 39.8% | N = 6481 | Clinical examination | Mid back pain |
|                       |                 |                                     |                          |        |              | Prevalence % (95%CI) 65.5 (64.4–66.7)                                     |
|                       |                 |                                     |                          |        |              | Localised % (95%CI) 0.06 (0.00–0.12)                                     |
|                       |                 |                                     |                          |        |              | Posterior shoulder (includes upper thoracic)                             |
|                       |                 |                                     |                          |        |              | Prevalence % (95%CI) 75.3 (74.3–76.4)                                     |
|                       |                 |                                     |                          |        |              | Chest pain |
|                       |                 |                                     |                          |        |              | Prevalence, % (95%CI) 18.9 (17.9–19.8)                                    |
|                       |                 |                                     |                          |        |              | Localised % (95%CI) 0.05 (0.00–0.10)                                     |
| Holm2007[17]          | Cohort          | WAD Approx. 10 days to 6 months     | Age n (%) ≥ 40 n = 21 (21) 30–39 n = 18 (22) 18–29 n = 17 (20) Females = 38 (24%) | N = 56 | Clinical examination | Chest pain prevalence, n (%) |
|                       |                 |                                     |                          |        |              | Baseline -                                                            |
|                       |                 |                                     |                          |        |              | 6-weeks 2(6)                                                          |
|                       |                 |                                     |                          |        |              | 4-months 1(4)                                                        |
|                       |                 |                                     |                          |        |              | 8-months 2(12)                                                       |
|                       |                 |                                     |                          |        |              | 12-months 5(22)                                                      |
|                       |                 |                                     |                          |        |              | Thoracic pain prevalence, n (%) |
|                       |                 |                                     |                          |        |              | Baseline 29 (52)                                                      |
|                       |                 |                                     |                          |        |              | 6-weeks 28 (80)                                                      |
|                       |                 |                                     |                          |        |              | 4-months 24 (86)                                                     |
|                       |                 |                                     |                          |        |              | 8-months 16 (94)                                                     |
|                       |                 |                                     |                          |        |              | 12-months 20 (87)                                                    |
| Ide2001 [46]          | Cohort          | WAD 1 week to 6 months              | Mean, range age Male = 36.1, Female = 35.7 14–61 years | N = 119 | Cervical radiographs Clinical examination | Non-brachial plexus irritation n = 74 Brachial plexus irritation n = 45 |
| Johansson2015[2]      | Cohort          | WAD                               | Median age 35.7 (25.3–47.2) years Females = 2484 (66.9%) | N = 3711 | Clinical examination | Mid back pain present in 3711 individuals (43%) |
|                       |                 |                                     |                          |        |              | Incidence 236/100,000                                                  |
|                       |                 |                                     |                          |        |              | Baseline pain rating 6 (5–8)                                           |
|                       |                 |                                     |                          |        |              | 23% not recovered at one year                                          |

(Continued)
| Author & Date | Design | Sample | Age | Gender | Conclusion | Findings |
|--------------|--------|--------|-----|--------|------------|---------|
| Kai 2001 [47] | Cohort | No data reported | N = 110 | Gender | No data reported | N = 110 |
| Kall 2008 [48] | Longitudinal study using data from previous RCT | N = 47 | Mean (range) age 31 (18–61) years | Gender | Female n = 30 (64%) | Male n = 17 (36%) |
| Klein 2001 [49] | Case control | N = 46 | Mean (SD) 36.4 (10.1) years | Gender | Female 67% | Male 33% |
| Koelbeck 1999 [50] | Case control | WAD N = 11 | Mean (range) 42 (26–69) years | Gender | Female n = 7 | Male n = 4 |
| Magnusson 1994 [51] | Cohort | N = 38 | Mean (range) age 33 (17–52) years | Gender | Unilateral n = 9 (23.7%) | Bilateral n = 3 (7.9%) |

For more details, please refer to the full text.
| Author & Date | Design | WAD patients | Age | Gender | Sample | Assessment | Findings |
|--------------|--------|--------------|-----|--------|--------|------------|----------|
| McLean, 2014 [52] | Cohort | WADI & II Data for acute (<24 hours injury) and sub-acute (6 weeks) | Median (range) age: 36 (18–65) years | Females 60.7% (Females 62.6% 6 weeks sub-acute) | Acute N = 948 Chronic n = 711 (non-litigant group) 6 weeks: N = 859 | Participant interview | Pain (moderate or severe NRS 4)6 weeks • Upper back 21% (18–24%) • Shoulder (including posterior upper thoracic) 23% (20–26%) • Chest 8% (6–10%) No data available for other time points, authors contacted |
| Myran2011 [53] | Cohort | Chronic WAD | Age Mean across subgroups: 40.8–56.0 | Female: 44.3–67.1% | N = 46,895 | Questionnaire | Chest/abdomen Men Total 972 • N = (%) 66 (7.0) • OR (95%CI) 3.6 (2.4, 5.2) Women Total 1543 • N = (%) 107 (6.9) • OR (95%CI) 7.1 (4.9, 10.4) Upper back Men Total 1421 • N = (%) 125 (8.8) • OR (95%CI) 5.0 (3.7, 6.7) Women Total 3,361 • N = (%) 235 (7.0) • OR (95%CI) 5.9 (4.4, 7.8) |
| Omar, 2007 [54] | Case report | Chronic WADII (6 months) | 30 year old male | N = 1 | • Clinical examination. • MRI • Electromyography • Nerve conduction studies | Left brachial plexus lesion • Denervation of L. serratus anterior and reduced motor unit recruitment (Winging scapular) |
| Sterling 2002 [55] | Case control | Chronic WADII & III >3months | WAD | Mean (SD) 37.43 (9.3) years Female n = 127 • Male n = 29 | WAD N = 156 | Clinical examination | Brachial plexus provocation test ROM (from -180degrees) Mean (95% CI) • WAD -26.21 (-28.05, -24.37) • Control -12.92 (-15.24, -10.6) VAS (0–10) • WAD 4.93 (4.6, 5.3) • Control 2.62 (2.2, 3.04) WAD vs control Significantly higher VAS and less ROM on elbow extension in WAD group (p<0.001) Subgroups within WAD: • Group 1: Whole arm pain reproduced with BPPT n = 40 • Group 2: Arm pain not reproduced with BPPT n = 54 • Group 3: No arm pain n = 62 Elbow extension significantly less in group 1 then group 2 Elbow extension significantly less and VAS significantly higher in group 1 vs group 3 No difference in ROM or VAS between group 2 and 3 |
| Control | Mean (SD) 38.95 (14.47) years | Female n = 50 • Male n = 45 | Control N = 95 |

(Continued)
| Author & Date | Design | WAD patients | Age | Gender | Sample | Assessment | Findings |
|---------------|--------|--------------|-----|--------|--------|------------|----------|
| Sterling 2003a [56] | Case control | WADII-III (< 1 month) | WAD | Mean (SD) 36.27 (12.69) years | Female n = 45, Male n = 21 | WAD N = 66 | • Clinical examination  • Electromyography | SCM activity  Increased SCM muscle activity across all point and disability ratings with higher disability resulting in heighten SCM activity  • Recovered group n = 25, NDI<8, 29 ±4%  • Mild pain and disability n = 22 NDI 10–28, 27±3%  • Moderate/severe pain and disability n = 19, NDI >30, 40±4%  • Control n = 20, 16±3% |
| Sterling 2003b(same as 2003a)[57] | Case control | Sub-acute WADII-III | WAD | Mean (SD) 36.27 (12.69) years | Female n = 56, Male n = 24 | WAD N = 80 | Clinical examination | BPTT (from 180-degree extension elbow)  • <1 months post injury  • Recovered group -23.95 (2.4) degrees, VAS 1.8 (0.4)  • Mild pain -33.97 (2.6) degrees, VAS 3.2 (0.5)  • Moderate/severe pain -34.27 (3.4) degrees, VAS 4.1 (0.5)  • Control -20.67 (3.12) degrees, VAS 1.8 (0.4)  Mild pain recovered and no different from controls at 2 months 6 months  Moderate/severe pain: continued to have higher VAS 3.4 (1.0) and reduced elbow extension (no data provided) |
| Sterling 2004 [12] | Case control | Acute WADII-III <1 month | WAD | Mean (SD) 33.5 (14.7) years | Female n = 56, Male n = 24 | WAD N = 80 | Clinical examination | SCM activity (%)  • Control 13(3)%  • Mild 32(3)%  • Moderate 29(4)%  • Severe 47(4)%  BPTT (mean (SD) from 180-degree extension elbow + VAS mean (SD))  • Control -21.4 (10.8), VAS 1.7 (1.7)  • Mild -26.7 (17.7), VAS 1.8 (1.7)  • Moderate -31.3 (14.9), VAS 3.0 (1.8)  • Severe -36.5 (1.8), VAS 4.3 (1.6)  Significantly decreased elbow extension ROM and higher VAS in severe pain group versus the other 2 whiplash groups |
| Sterling 2005 (same population 2004)[58] | Cohort | Chronic WADII-III (96% WAD II) | WAD | Mean (SD) 36.27 (12.69) years | Female n = 56 | N = 80 | Clinical examination | Thoracic pain prevalence 54% |
| Sterling 2009 [59] | Cohort | Acute WADII-III | WAD | Mean (SD) 36.27 (12.69) years | Female n = 54 | N = 85 | Clinical examination | BPTT (from 180-degree extension elbow, mean (SD))  • S-LANSS >12 n = 29–56.5 (28)  • S-LANSS <12 n = 56–35.3 (19) |

(Continued)
Table 1. (Continued)

| Author & Date | Design | WAD patients | Age Gender | Sample | Assessment | Findings |
|---------------|--------|--------------|------------|--------|------------|---------|
| Wenzel 2009 [60] | Case control | Chronic WAD (94% >2 years) | WAD Mean (SD) 47.6 (14.9) Female 48.4% | WAD N = 785 | Questionnaire and clinical examination | Control group n = 2.060 (0.3%) CWAD n = 117 (41%) Odds ratio (95% confidence interval) 7.84 (6.26–9.82) |
| | | | Control Mean (SD) 47.9 (16.7) Female 50.7% | Control N = 52,208 | | |
| Wirth 2014 [61] | Case control | Chronic WAD | WAD Mean (SD) age 45 (10.05) years Females n = 4 Males n = 3 | N = 7 (subset from larger cohort of neck pain patients) | Clinical examination | Thoracic neutral posture and mobility (raw data provided by authors) |
| | | | | | | WAD • Thoracic neutral 30.14 (12.86) degrees • Thoracic flexion-extension 50 (14.55) degrees • Chest expansion axilla 4.72 (2.53) cm • Chest expansion xiphoid 5.21 (2.92) cm Control • Thoracic neutral 36.75 (11.32) degrees • Thoracic flexion-extension 43.76 (16.09) degrees • Chest expansion axilla 5.86 (2.34) cm • Chest expansion xiphoid 5.75 (2.33) |
| Yeung 1997 [62] | Case control | WAD <12mths (suggestive WADI or II) | WAD Mean 25.3 years Female n = 20 | WAD N = 20 | Clinical examination | Stage 1: • WAD n = 12 (60%), Control n = 2 (5%) (n = 8 of WAD group reported mid-thoracic symptoms) Stage 2: WAD (90%), Control n = 2 (5%) reported symptoms (WAD n = 15 (75%), Control n = 23 (57.5%) reported mid-thoracic symptoms Stage 3: • Pain response in both groups mid-thoracic Stage 4: • WAD n = 17 (85%) reported mid-thoracic symptoms • Control n = 33 (82.5%) reported mid-thoracic symptoms Stage 5: Evidence of greater proportion of mid-thoracic pain reduction in WAD group compared to control. Stage 6, 7: • no data Mean (SD) ROM degrees • Control L 74 (3.82), R 74 (4.57) • WAD L 68 (3.3), R 68 (4.60) |

AIS: Abbreviated Injury Scale BPI: brachial plexus irritation, BPTT: brachial plexus tension test, CCFT: cranio cervical flexion test, CT: computerised tomography, EMG: electromyography, MRI: magnetic resonance imaging, MTP: myofascial trigger point, NBPI: no brachial plexus irritation, NDI: Neck Disability Index, NRS: numerical rating scale, OR: odds ratio, RCT: randomised controlled trial, ROM: range of movement, SCM: sternocleidomastoid muscle, TOS: thoracic outlet syndrome, TDH: thoracic disc herniation, WAD: whiplash associated disorders, WDQ: Whiplash Disability Index

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Table 2. Overview of included studies.

| Author       | Measurement and summary outcome                                                                 | Sample size | Acute/ sub acute | Chronic | WADII/ WADII/ WADII/ III |
|--------------|--------------------------------------------------------------------------------------------------|-------------|------------------|---------|--------------------------|
| N = 37 papers|                                                                                                 |             |                  |         |                          |
| **Thoracic pain prevalence**                                                                 |                         |             |                  |         |                          |
| Yeung 1997   | 75% (during slump)                                                                              | 20          | x                | x       |                          |
| Koelbeck 1999| No difference light touch (reduced PPT, hyperalgesia & referral)                                | 11          | x                |         |                          |
| Bergland 2001| 15.3%                                                                                           | 242         | x                | x (minor)|                          |
| Hartling 2002| 74%                                                                                             | 380         | x                | x       |                          |
| Bock 2005    | 71% (alldynia)                                                                                  | 22          | x                | x       |                          |
| Sterling 2005| 54%                                                                                             | ***76       | x                | x       |                          |
| Holm 2007    | Acute 52%, chronic 80%                                                                           | 56          | x                | x       |                          |
| Wenzel 2009  | 41%                                                                                             | 785         | x                |         |                          |
| Hincapie 2010| 66–75%                                                                                            | 6481        | x                |         |                          |
| Myran 2011   | 7–8.8%                                                                                          | 46,895      | x                |         |                          |
| Bortsov 2014 | 47%                                                                                             | 948         | x                | x       |                          |
| Cornips 2014 | Pain associated with herniated disc 4/10                                                        | 10          | x                |         |                          |
| McLean 2014  | 21% (upper thoracic/shoulder 23%)                                                                | 711         | x                | x       |                          |
| Johansson 2015|                                                                                                  | 3711        | x                | ?       |                          |
| **Chest pain prevalence**                                                                                       |                         |             |                  |         |                          |
| Holm 2007    | Acute 0%, chronic 6%                                                                             | 56          | x                | x       |                          |
| Hincapie 2010| 19%                                                                                             | 6481        | x                |         |                          |
| Myran 2011   | 6.9–7%                                                                                          | 46,895      | x                |         |                          |
| Bortsov 2014 | 19%                                                                                             | 948         | x                | x       |                          |
| McLean 2014  | 8%                                                                                              | 948         | x                | x       |                          |
| **Thoracic posture & mobility**                                                                                  |                         |             |                  |         |                          |
| Kall 2008    | Flexion hypomobility                                                                            | 47          | x                | x       | x                        |
| Helgadottir 2011a|                                                                                             | No change 23 | x                |         |                          |
| Wirth 2014   | Reduced kyphosis (chest expansion)                                                               | 7           | x                |         |                          |
| **Thoracic outlet syndrome prevalence**                                                                            |                         |             |                  |         |                          |
| Capistrant 1976|                                                                                                 | 86%         | 35               | x       |                          |
| Capistrant 1986|                                                                                                 | 36%         | 111              |       | x                        |
| Magnusson 1994|                                                                                                 | 32%         | 38               | x       | x                        |
| Kai 2001     | 74%                                                                                             | 110         | x                | x       | x                        |
| Alexandre 2005|                                                                                                 | Positive 24 | x                | x       | (mild)                   |
| **Brachial Plexus test**                                                                                         |                         |             |                  |         |                          |
| Ide 2001     | Prevalence 38%                                                                                   | 119         | x                | x       |                          |
| Sterling 2002| Positive                                                                                         | 156         | x                |         |                          |
| Sterling 2003b| Positive                                                                                         | **80        | x                | x       | x                        |
| Sterling 2004| Positive                                                                                         | 80          | x                |         | x                        |
| Omar 2007    | Brachial plexus lesion                                                                            | 1           | x                |         | x                        |
| Chien 2009   | Positive                                                                                         | 31          | x                |         | x                        |
| Sterling 2009| Positive                                                                                         | 85          | x                |         | x                        |
| Ferrari 2010 | Positive                                                                                         | 69          | x                |         | x                        |
| **Muscle activation**                                                                                            |                         |             |                  |         |                          |
| Bodack 1998  | Weak mid and lower trapezius                                                                      | 1           | x                |         | x                        |
| Klein 2001   | SCM muscle activation: normal                                                                     | 46          | x                | x       | (mainly)                 |
| Sterling 2003a| SCM muscle activity heightened                                                                     | **66        | x                |         | x                        |
specifically associated with central sensitisation (allodynia) where pain prevalence was 71% in
individuals with CWADI/II [33].

**Chest pain.** Prevalence of chest pain in acute/sub-acute was reported to range 0.0–19%
[11, 14, 17, 52], although when considered as part of a widespread pain presentation ranged
9–19% [11, 14]. In one study where they only considered individuals with numerical rating
scale (NRS 0–10) 4+ chest pain prevalence was lower at 8% [52]. In CWAD prevalence rates
for chest pain ranged 6–22% [17, 53] although this reflects a, broad timescale with one study
reporting results 6 month post injury [17] to one exploring prevalence at any time point fol-
lowing injury [53]. Drawing definitive conclusions on prevalence of chest pain is difficult
given variation in approaches used to record pain (pain drawings, VAS, etc.), time points post
injury, sample heterogeneity and the overall methodological low quality of research. This may
also be a related to the focus of this review, being to those with mild to moderate presentations
of WAD where studies including WADIV or fractures were excluded.

**Thoracic posture.** Evidence of thoracic postural dysfunction is inconclusive given con-
flicting findings from a small number of studies of low methodological quality evidence where
postural assessment was not a primary focus [44, 61]. Future studies should consider the use of
a gold standard measure for postural evaluation [63].

**Thoracic mobility and chest mobility.** There is a notable gap in the evidence exploring
thoracic and chest mobility in WAD, with just two studies (n = 54) of very low quality suggest-
ing a trend for reduced chest mobility (p > 0.05) and flexion hypomobility at the cervico-tho-
racic junction in women. In terms of thoracic mobility, evidence from one study (n = 7) [61]
suggests a slight increase in thoracic flexion-extension, although with such a small sample and
lack of inclusion of a valid approach to quantify thoracic mobility, meaningful conclusions
cannot drawn.

**Thoracic outlet syndrome in CWAD.** Five studies found, a prevalence of 31–74+% [31,
35, 36, 47, 51] of thoracic outlet syndrome in CWAD. Although this suggests a relatively high
prevalence, the methodological quality of included studies was generally poor (<4/9), resulting
in a very low rating of quality according to GRADE.

**Brachial plexus.** Acute/sub-acute WAD
| Author          | Dysfunction & sample size | Classification and time post injury Disability Pain | Summary results | Quality | Comments/ study quality |
|-----------------|----------------------------|----------------------------------------------------|-----------------|---------|------------------------|
| Alexandre 2005 | Thoracic outlet syndrome N = 24 | Mild Mean (range) 11 (2–48) mths | Brachial plexus entrapment due to TOS No Sub group cervical spine injury included | No non exposed cohort | No Patient examination and ED documents | No No Yes Unclear Private neurological practice |
| Bismil 2012    | Trapezius dysfunction n = 25 | WADII > 6 mths, but not reported | Trapezius myofascial entheseal dysfunction (myofascial pain and trigger points) Yes No non exposed cohort | Yes Patient examination | No No No | Yes No Yes Yes Unclear Clinical examination in medical legal practice Limited sample details Limited information on examination and outcome measures |
| Bock 2005      | Thoracic allodynia N = 22 | WADI & II3-18 mths | Thoracic allodynia evident in 70.97% (more in lower spinal segments, T8-A10) Yes No non exposed cohort | Yes Recruitment from private physiatry/pain management practice | No No No | Yes No No No Yes Yes No follow up? No follow up? Aim focus to reliability of measures |
| Bortsov 2014   | Thoracic pain N = 948 | WADI & II 6 weeks, 3,6,12 mths NR56 weeks 3.8 (2.8) 6 months 3.1 (2.8) 1 year 3.2 (2.9) | Thoracic and chest pain prevalence at 6 weeks 47% and 19% respectively | Yes No non exposed cohort | Yes ED department interview | Unclear No reference to prior msk injury Yes Adjusted for age and sex Unclear Yes Range of approaches Yes Yes Recruitment from ED Limited upper back data included with axial data Selective reporting of results: time points, regions |
| Capistrant1976 | Thoracic outlet syndrome N = 35 | Unknown Acute 3.5 mths (max 8 mths) Chronic mean 29 mths (inc n = 1 16 years) | Thoracic outlet syndrome n = 30/35 (86%) No With signs of TOS. Unclear re stage & severity | No No exposed cohort | Yes Private neurological practice | No No No Yes NCS records Yes Yes Private neurological practice Clarity re stage and WAD classification Inconsistent follow up periods Not accounted for other variables |

(Continued)
| Author | Dysfunction & sample size | Classification and time post injury | Summary results | Quality | Comments/ study quality |
|--------|--------------------------|--------------------------------------|-----------------|---------|------------------------|
| Capistrant 1986 | Cervical Strain injuries N = 111 of whom N = 40 was TOS | Unknown? Chronic 24month period | Thoracic outlet syndrome prevalence 36% | No non exposed cohort No | No non exposed cohort Yes | Private neurological practice. | No | No | Yes | NCS records | Yes | Unclear | Clarity re stage and WAD classification Variable follow up periods Not accounted for other variables Limited details of sample, follow up |
| Ferrari 2010 | Brachial plexus N = 69 | WADI & II <1 week and chronic (3 months) WQDQ (23) VAS 2.2 | Brachial plexus provocation test | Yes | Acute WAD | No | non exposed cohort | No non exposed cohort | No | | No | Yes | NCS records | Yes | Unclear | 2 loss to follow up Clear recruitment, reporting attrition and sample details Prognostic study Incomplete data for all time points: baseline BPTT omitted |
| Hartling 2002 | Upper back pain N = 140 | Sub-acute WADI-III | Upper back pain 74.6% | Yes | From earlier paper | Yes | From ED | Yes | From earlier paper | No | No | Yes | Yes | 87.9% follow up | Yes | 87.9% follow up | Derivation of a clinical prediction rule study rather than cohort |
| Holm 2007 | Upper back pain N = 56 | Acute chronic WAD | Chest pain prevalence Acute 0% Chronic (6 weeks) 6% Thoracic pain prevalence Acute 52% Chronic 80% | No Claimants | No non exposed cohort | No | Claimants | No | Claimants | Unclear | No information | Yes | No | Unclear | Questionnaire | Yes | Yes | 63% for all time points Insurance claims or filed claim |
| Hincapie 2010 | Thoracic pain N = 6481 | WADI, II <30 days post traffic injury | Thoracic pain prevalence 65.5–78.3% Chest pain prevalence 18.9% | No Litigants | No non exposed cohort | No | | | | Yes | | Yes | Yes | No follow up? | Yes | Yes | No follow up? Insurance claimants or file claim Analysed pain drawings linked to pre-existing symptoms- no data reported | (Continued) |
| Author          | Dysfunction & sample size | Classification and time post injury | Disability | Pain | Summary results    | Quality       | Selection           | Comparability   | Exposure /Outcome | Comments/Study quality |
|-----------------|---------------------------|-------------------------------------|------------|------|--------------------|---------------|--------------------|-----------------|-------------------|-----------------------|
| Ide2001         | Brachial plexus irritation N = 119 | WADI week to 6 months            | Brachial plexus irritation prevalence n = 45/74 (61%) (associated with poor outcome) | Unclear | No non exposed cohort | Yes            | No                 | No              | No                | Yes (2 loss to follow up)  |
| Johannsson2015  | Thoracic pain N = 3711    | WAD < 42 days post injury when claim filed | Thoracic spine pain 43% Baseline pain rating 6 (5-8) 2.8% not recovered after one year | No     | Canadian provincial population | No            | Non exposed cohort | Yes              | Registered health care professional | Unclear (Data provided for subgroups)  |
| Kai2001         | Thoracic outlet syndrome N = 110 | WAD                          | Neurogenic thoracic outlet syndrome prevalence n = 81/110 (74%) | Unclear | No non exposed cohort | Yes            | No                 | No              | No                | No (Late whiplash)  |
| Kall2008        | Cervico-thoracic mobility N = 47 | WADI-II (sub-acute)            | Concluded women with subacute WAD C7-T1 flexion hypomobility | Yes     | Self selection | No            | Non exposed cohort | Yes              | Yes Clear eligibility criteria | No (Unclear)  |
| Magnusson1994   | Thoracic outlet syndrome N = 38 | Chronic WADI-II Mean (range) 17 (0-44) months | Thoracic outlet syndrome prevalence 31.6% | No     | Some had surgery | Yes            | Intervied by author | Yes              | Yes Clear eligibility criteria | No (Unclear)  |

(Continued)
| Author          | Dysfunction & sample size | Classification and time post injury | Summary results                                                                 | Quality                                                                 | Comments/ study quality |
|-----------------|---------------------------|-------------------------------------|---------------------------------------------------------------------------------|-------------------------------------------------------------------------|-------------------------|
| McLean 2014     | Thoracic, chest pain N = 948 | Acute WAD WAD I & II 24 hours to 6 weeks | Thoracic pain prevalence 2%, shoulder 23%, chest 8% No English speakers, non Hispanic white population only | Yes ED department interview Unclear No reference to prior musculoskeletal injury | Yes Yes Yes N/A Non litigant population Clear eligibility criteria Only individuals from ED Payment for participation |
| Myran 2011      | Upper back and chest pain prevalence N = 46,895 | WAD No other details | Chest/abdomen pain prevalence Men 7%, Women 6% Upper back pain prevalence Men 8.8% Women 7.0% | Unclear Questionnaire as part of health survey Unclear No reference to prior musculoskeletal injury | Yes Yes Yes N/A Non litigant population Clear eligibility criteria Only individuals from ED Payment for participation |
| Sterling 2005   | Thoracic pain N = 76     | WADII-III 6 months NH1 34.15 (2.37) VAS 3 (1.2) | Thoracic pain prevalence 54% No non exposed cohort Yes Recruited primary care, ED and community | Yes Yes Yes Controls for other factors in analysis | Unclear Yes Yes Loss to follow up n = 4 Recruited primary care, ED and community Clear eligibility criteria Assessor blinding unclear Loss to follow up suggested 4/80, but numbers unclear |
| Sterling 2009   | Brachial plexus N = 85   | Acute WADII-III 2.6 (1.2) weeks | Brachial plexus provocation test positive (and associated with neuropathic pain presentation) | Yes Acute | Yes Unclear Yes Unclear Yes Recruited primary care, ED and community Assessor blinding unclear | Yes Unclear Yes Recruited primary care, ED and community Assessor blinding unclear No mention of any losses to follow up. Control for age and gender unclear |
### Table 4. Risk of bias assessment: Thoracic dysfunction in whiplash associated disorders: A systematic review and meta-analysis case control studies

| Author          | Dysfunction & classification | Sample size | Summary results | Quality | Comments/study quality |
|-----------------|------------------------------|-------------|-----------------|---------|------------------------|
| Bergholdt2001   | Thoracic pain               | N = 348     | Mend 70%        | Poor    | No patient demographics funded by insurance company |
| Castaldo2014    | Myofascial trigger points   | N = 40      | WAD II & III Mean (SD) 57.12 (14.11) mthsVAS 5.39 (0.42) | Poor    | Compared with MNP Not clear re centre for recruitment Inc. exclusion criteria clear |
| Chien2009       | BPPT                         | N = 31      | WAD II 15 (11) months post injury NDI 4.5 (1.8) | Fair    | Other factors not controlled for e.g. psychological factors WAD group moderate disability |
| Ettlin2008      | Myofascial trigger points   | N = 47      | Unknown Mean (SD) 1.47 (1.8) yearsVAS 5.62 (4.08) | Poor    | Controls recruited from one of the sites Unknown characteristics More females in WAD group WAD participants had physiotherapy |
| Fernandez-Myofascial trigger points | N = 20 | WAD II Mean (SD) 26.78 6 (3.8) daysNDI 68.5 (9.7) VAS 6.2 (2.6) | Fair    | Other factors not controlled for e.g. psychological factors WAD group severe disability |
| Perez2012       | Myofascial trigger points   | N = 20      | WAD II Mean (SD) 1010 (0.6) VAS 6 (2) | Fair    | Other factors not controlled for e.g. psychological factors WAD group severe disability |
| Helgadottir2011a| Thoracic Alignment (mid thoracic curve) | N = 23 | WAD II 6 (3.9) | Poor    | VAS not provided although included Recruitment method of control unclear |
| Helgadottir2011b| Muscle function (mid & lower trapezius, serratus anterior) | N = 27 | WAD II >6monthsNDI 3 (10) VAS 6 (2) | Poor    | No reference to blinding VAS not provided Recruitment method of control unclear |
|                 |                              |             |                 |         |                        |

(Note: This table continues on the next page for additional details on selection, comparability, and exposure/outcome criteria for each study.)
| Author            | Dysfunction & sample size | Classification and time post injury | Summary results | Quality | Comments/ study quality |
|-------------------|---------------------------|-------------------------------------|-----------------|---------|-------------------------|
| Klein 2001        | Muscle activation at-emergent sampling N = 46 | Chronic WAD II-III 3.17 (2.7) months | No evidence of earlier SCM activity during axial rotation | Yes | GP referral | Recruitment of controls unclear | Controls younger than WAD III group: 39% men, control 42% |
| Koelbeck 1999     | Pain over infraspinatus region N = 11 | Chronic WAD II mean (range) duration 4 years, 5 months to 1 year, 7 months to 5 years | Reduced pressure pain threshold in WAD: muscle hyperesthesia and diffuse pain referral | Yes | Referral to pain clinic | Recruitment from pain centre: Control recruitment unclear |
| Sterling 2002     | Brachial plexus N = 156 | Chronic (>3 months) WAD II-III Unclear | Brachial plexus provocation test positive in WAD | Unclear | Referral to research centre. | Time following injury unclear: No reference to Blinding Clinical examination done. No independent validation |
| Sterling 2003a    | SCM activity N = 86 | WAD II & III:3 months NDI from 3.00– 47.9 | SCM activity increased in those with mod/severe symptoms + mild: recovered and controls: over time points to 3 months post injury | Unclear | A&E, community, primary care, No reference to primary records | No reference to Blinding Control for other psychological variables |
| Sterling 2003b    | BPTT N = 80 | Sub-acute WAD II-III | BPTT: those with positive test within 1 month of injury higher pain levels at 6 mths | Unclear | A&E, community, primary care | No reference to Blinding Control for other psychological variables |
| Sterling 2004     | SCM activity and BPTT N = 80 | Acute WAD & BI:1 month NDI 1.5–69.5 | SCM increased in WAD and with increasing symptom severity BPTT positive in WAD and with increased symptom severity | Unclear | A&E, community, primary care | No reference to Blinding Control for other psychological variables |
| Wear 2009         | N = 785 | Chronic WAD >2 years | Thoracic spine pain prevalence 41% | No | From a wider health study | Large sample as part of health study: Controlling for other variables unclear |

(Continued)
| Author | Dysfunction & sample size | Classification and time post injury Pain duration, disability and pain intensity | Summary results | Quality | Comments/study quality |
|--------|---------------------------|--------------------------------------------------------------------------------|-----------------|--------|-----------------------|
| Wirth 2014 | Chest mobility, Thoracic flexion, extension N = 7 | Chronic WAD 1–5+ years NDI 12 (7.1) | Reduced thoracic kyphosis & small reduction in chest expansion | No Recruited from sports centre | No No Not reported Yes Groups balanced No No No blinding | Yes Unclear Recruit from sports clubs and medical centres No information re blinding |
| Yeung 1997 | Slump Test: positive in all WAD (<12 months, suggestive WADI or II) Unclear | | | | Yes Clear exclusion criteria Yes No No blinding | Yes Unclear Only females Unclear recruitment for WAD and control Part of a reliability study |
| Outcome                                      | Studies                                      | Findings Prevalence % (95% confidence interval) unless stated | Studies                                      | Overall GRADE                      |
|----------------------------------------------|----------------------------------------------|-------------------------------------------------------------|----------------------------------------------|------------------------------------|
| Thoracic spine pain in acute/sub-acute WAD  | Bodack 1998                                  | - Positive                                                  | 6 cohort, 1 single case study                | Very low—due to risk of bias, directness and precision |
| N = 11,577                                   | Hartling 2002                                | - Upper back pain 74.6%                                     |                                              |                                    |
|                                              | Holm 2007                                    | - 52%                                                       |                                              |                                    |
|                                              | Hincapie 2010                                | - Mid back 65.5 (64.4–66.7) - Upper thoracic 75.3 (74.3–76.4) |                                              |                                    |
|                                              | * Bortsov 2014 (Mild)                        | - Mid back 47% (18% widespread, 29% localised)              |                                              |                                    |
|                                              | * McLean 2014 (WADI/II) (moderate or severe pain NR54) | - Mid back 21% (range 18–24%) - Upper back 23% (range 20–26%) |                                              |                                    |
|                                              | Johansson 2015                               | - 43%                                                       |                                              |                                    |
| Thoracic spine pain in chronic WAD           | Yeung 1997 (WADI/II)                         | - Slump                                                     | 5 cohort, 3 case control, 1 case series      | Very low—due to risk of bias, precision, consistency and directness |
| N = 48,117                                   | Koelbeck 1999 (WADI)                         | - No different controls                                     |                                              |                                    |
|                                              | Bergland 2001 (Minor)                        | - 15.3% (10.4–21.5)                                        |                                              |                                    |
|                                              | Bock 2005 (WADI/II)                          | - 71% (allodynia)                                           |                                              |                                    |
|                                              | Sterling 2005 (WADI/III)                     | - 54%                                                       |                                              |                                    |
|                                              | Holm 2007                                    | - 4 months 86%, -8 months 94%, -12 months 87%               |                                              |                                    |
|                                              | Wenzel 2009                                  | - 41%                                                       |                                              |                                    |
|                                              | Myran 2011                                   | - men 8.8% - women 7%                                       |                                              |                                    |
|                                              | Cornips 2014                                 | 10 previously asymptomatic individuals significant pain     |                                              |                                    |
| Thoracic spine pain in chronic WAD I/II     | Koelbeck 1999 (WADI)                         | - No different controls                                     | 3 cohort, 1 case control                     | Very low—due to risk of bias, precision, consistency and directness |
| N = 655                                      | Bergland 2001 (Minor)                        | - 15.3% (10.4–21.5)                                        |                                              |                                    |
|                                              | Hartling 2002                                | - Upper back pain 74.6%                                     |                                              |                                    |
|                                              | Bock 2005 (WADI/II)                          | - 71% (allodynia)                                           |                                              |                                    |
| Thoracic spine pain in chronic WAD II/III   | Sterling 2005 (WADI/III)                     | - 54%                                                       | 1 cohort                                     | Low??                              |
| N = 76                                       |                                              |                                                             |                                              |                                    |
| Chest pain in acute/sub-acute WAD           | Holm 2007                                    | - 0%                                                        | 4 Cohorts                                   | Very low—due to risk of bias, precision, consistency and directness |
| N = 7485                                     | Hincapie 2010                                | - Localised 0.05 (0.00–0.10) - widespread 18.9 (17.9–19.8) |                                              |                                    |
|                                              | * Bortsov 2014 (mild)                        | - 19% (10% localised -9% widespread)                        |                                              |                                    |
|                                              | * McLean 2014 (WADI/II)                      | - 8% (6–10%) (moderate or severe pain)                      |                                              |                                    |

(Continued)
Table 5. (Continued)

| Outcome                           | Studies          | Findings                              | Studies | Overall GRADE |
|-----------------------------------|------------------|---------------------------------------|---------|---------------|
| Chest pain in chronic WAD        | Holm 2007        | -6-weeks 6%, 4-months 4%, 8-months 12%, 12-months 22% | 2 cohorts | Very low—due to risk of bias, precision, directness |
| N = 46,951                        | Myran 2011       | -men 7%, women 6.9%                   |         |               |

Notwithstanding that evidence is drawn principally from one research group, there is evidence of thoracic dysfunction in relation to the brachial plexus provocation test (BPPT) in WADI-III. From the research by Sterling et al [12, 57, 59], there is evidence of a negative association between self-report symptom severity (VAS) and range of elbow extension during the BPPT in chronic WAD. Moreover, the extent of this dysfunction is in turn related to the degree of pain and disability, with those participants presenting with higher levels of self-reported pain and disability (NDI) having greater levels of dysfunction during BPPT.

**Chronic WAD**

For participants with CWADII and/or III, evidence indicates dysfunction detected during the BPPT, with pain levels and restriction in elbow extension almost double those found in asymptomatic controls [38, 55]. Furthermore, those with higher levels of self-reported pain and disability (NDI>30) continued to have evidence of dysfunction 6 months after the injury which was not seen in the mild group who were no different to the recovered group at 2 months [57]. Although quality of individual studies varied (4-6/9), the overall body of evidence for dysfunction of the brachial plexus remains very low overall, primarily due to risk of bias of the included studies.

**Muscle activation.** There are limited and very variable findings of thoracic muscle dysfunction (activation) in WAD with studies investigating a relatively small number of muscles: sternocleidomastoid [12, 49, 56]; serratus anterior [45]; middle and lower fibres of trapezius [45, 54]. Although it is difficult to derive meaningful conclusions with respect to serratus anterior and trapezius, there is evidence supporting changes in sternocleidomastoid muscle activation with heightened levels of activation during a task of cranio-cervical flexion; this increase in sternocleidomastoid activity however, was not seen during neck rotation [49]. There appears to be a positive relationship between sternocleidomastoid activation and higher levels of pain severity, with participants with CWADII/III and moderate to severe levels of disability demonstrating increased levels of sternocleidomastoid activation of between 27–47% [12, 56].

Table 6. Posture and mobility.

| Outcome                          | Studies          | Findings                              | Grade          | Overall GRADE |
|----------------------------------|------------------|---------------------------------------|----------------|---------------|
| Thoracic posture in chronic WAD  | Helgadottir 2011a (WADI) | -No change                           | 2 Case control | Very low: due to risk of bias, precision, consistency and directness |
| N = 30                           | Wirth 2014       | -Reduced kyphosis                     |                |               |
| Thoracic and chest mobility in chronic WAD | Kall 2008 | -Flexion hypomobility in women | 1 cohort study, 1 case control | Very low: due to risk of bias, precision, consistency and directness |
| N = 54                           | Wirth 2014       | -Reduced chest mobility, -Slight increase in thoracic mobility |                |               |

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## Table 7. Thoracic outlet syndrome and brachial plexus.

| Outcome | Studies | Findings [TOS: Prevalence % (95% confidence interval); Brachial plexus provocation test (BPPT) unless stated] | Grade | Overall GRADE |
|---------|---------|-------------------------------------------------------------------------------------------------------|-------|---------------|
| Thoracic outlet syndrome in chronic WAD | Capistrant 1976 | -86%                                                                                                     | 5 Cohort studies | Very low: due to risk of bias, directness, precision, reporting bias |
| | Capistrant 1986 | -36%                                                                                                     |                   |               |
| | Magnusson 1994 | -31.6%                                                                                                   |                   |               |
| | Kai 2001 | 74%                                                                                                      |                   |               |
| | Alexandre 2005 | - Positive secondary to BPI                                                                                 |                   |               |
| Brachial Plexus in all WAD (n = 620) | Ide 2001 | BPIT 38%                                                                                                 | 4 case control, 3 cohort | Very low: due to risk or bias, directness and precision |
| | Sterling 2002 (WADI/III) Chronic | WAD -26.21 (95%CI -28.05, -24.37), VAS 4.93 (4.6, 5.3)                                                  |                   |               |
| | Sterling 2003b (WADI/III) Acute/sub-acute | <1 months post injury [mean (SD)] <br> - Recovered group -23.95 (2.4) degrees, VAS 1.8 (0.4) <br> - Mild pain -33.97 (2.6) degrees, VAS 3.2 (0.5) <br> - Moderate/severe pain -34.27 (3.4) degrees, VAS 4.1 (0.5) <br> - Control -20.67 (3.12) degrees, VAS 1.8 (0.4) <br> Mild pain recovered and no different from controls at 2 months |                   |               |
| | Sterling 2004 (WADI/III) Acute/sub-acute | Mean (SD) degrees/VAS <br> - Mild symptoms -26.7 (17.7), VAS 1.8 (1.7) <br> - Moderate symptoms -31.3 (14.9), VAS 3.0 (1.8) <br> - Severe symptoms -36.5 (11.8), VAS 4.3 (1.6) <br> - Control -21.4 (10.8), VAS 1.7 (1.7) |                   |               |
| | Sterling 2009 (WADI-III) Acute | Mean (SD)degrees <br> - S-LANSS >12–56.5 (28) <br> - S-LANSS <12–35.3 (19) |                   |               |
| | Chien 2009 (WADI) | WAD -22.3 (27.4) degrees VAS 2.4 (2.3) Control -11 (5.9) VAS 0.7 (1.1) |                   |               |
| | Ferrari, 2010 (WADI/II) | 3 months: <br> - VAS: mean (SD) 2.2 (1.2) <br> - Elbow extension: 41.5 (23) degrees |                   |               |
| Brachial Plexus In acute/sub-acute WAD (n = 419) | Ide 2001 | BPIT 38%                                                                                                 | 2 case control, 4 cohort | Very low: due to risk or bias, directness, precision |
| | Sterling 2003b (WADI/III) | <1 months post injury [mean (SD)] <br> - Recovered group (NDI <8) -23.95 (2.4) degrees, VAS 1.8 (0.4) <br> - Mild pain (NDI 10–28) -33.97 (2.6) degrees, VAS 3.2 (0.5) <br> - Moderate/severe (NDI >30) -34.27 (3.4) degrees, VAS 4.1 (0.5) <br> - Control -20.67 (3.12) degrees, VAS 1.8 (0.4) |                   |               |
| | Sterling 2004 (WADI/III) | Mean (SD)degrees/VAS <br> - Mild (NDI 15.6) -26.7 (17.7), VAS 1.8 (1.7) <br> - Moderate (NDI 39.5) -31.3 (14.9), VAS 3.0 (1.8) <br> - Severe (NDI 69.5) -36.5 (11.8), VAS 4.3 (1.6) <br> - Control -21.4 (10.8), VAS 1.7 (1.7) |                   |               |
| | Sterling 2009 (WADI-III) | Mean (SD)degrees <br> - S-LANSS >12–56.5 (28) <br> - S-LANSS <12–35.3 (19) |                   |               |
| | Ferrari, 2010 (WADI/II) | 3 months: <br> - VAS: mean (SD) 2.2 (1.2) <br> - Elbow extension: 41.5 (23) degrees |                   |               |

(Continued)
Table 7. (Continued)

| Outcome                          | Studies                                      | Findings [TOS: Prevalence % (95% confidence interval); Brachial plexus provocation test (BPPT) unless stated]                                                                 | Grade                   | Overall GRADE                              |
|----------------------------------|----------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|-------------------------|--------------------------------------------|
| Brachial Plexus In chronic WAD   | Sterling 2002 (WADI/III)                     | - WAD -26.21 (95%CI -28.05, -24.37), VAS 4.93 (4.6, 5.3) - Control -12.92 (95%CI -15.24, -10.6), VAS 2.62 (2.2, 3.04) - Mild (NDI 10–28): recovered and no different from controls at 2 months | 4 case control, 2 cohort | Very low: due to risk or bias, directness, precision |
|                                  | Sterling 2003b (WADI/III)                    | 6 months Moderate/severe (NDI >30): continued to have higher VAS 3.4 (1.0) and reduced elbow extension (no data provided)        |                         |                                            |
|                                  | Sterling 2004 (WADI/III)                     | Mean (SD)degrees/ VAS (pain & disability)                                                                                      |                         |                                            |
|                                  |                                              | • Mild (NDI 15.6) -26.7 (17.7), VAS 1.8 (1.7)                                                                                 |                         |                                            |
|                                  |                                              | • Moderate (NDI 39.5) -31.3 (14.9), VAS 3.0 (1.8)                                                                               |                         |                                            |
|                                  |                                              | • Severe (NDI 69.5) -36.5 (11.8), VAS 4.3 (1.6)                                                                                |                         |                                            |
|                                  |                                              | • Control -21.4 (10.8), VAS 1.7 (1.7)                                                                                        |                         |                                            |
|                                  | Chien 2009 (WADIII)                          | WAD -22.3 (27.4) degrees VAS 2.4 (2.3)                                                                                         |                         |                                            |
|                                  |                                              | Control -11 (5.9) VAS 0.7 (1.1)                                                                                            |                         |                                            |
| Brachial Plexus In WADI/III      | Sterling 2002 (WADI/III)                     | WAD -26.21 (95%CI -28.05, -24.37), VAS 4.93 (4.6, 5.3, 5.3) Control -12.92 (95%CI -15.24, -10.6), VAS 2.62 (2.2, 3.04) | 4 case control         | Very low: due to risk or bias, directness   |
| (n = 416)                        | Sterling 2003b (WADI/III) acute/sub-acute     | <1 months post injury [ROM mean (SD) (classified per pain & disability)]                                                      |                         |                                            |
|                                  |                                              | • Recovered group (NDI <8) -23.95 (2.4) degrees, VAS 1.8 (0.4)                                                                    |                         |                                            |
|                                  |                                              | • Mild pain (NDI 10–28) -33.97 (2.6) degrees, VAS 3.2 (0.5)                                                                    |                         |                                            |
|                                  |                                              | • Moderate/severe (NDI >30) -34.27 (3.4) degrees, VAS 4.1 (0.5)                                                                    |                         |                                            |
|                                  |                                              | • Control -20.67 (3.12) degrees, VAS 1.8 (0.04)                                                                                 |                         |                                            |
|                                  |                                              | Mild (NDI 10–28): recovered and no different from controls at 2 months                                                          |                         |                                            |
|                                  | Sterling 2003b (WADI/III) Chronic             | 6 months Moderate/severe (NDI >30): continued to have higher VAS 3.4 (1.0) and reduced elbow extension (no data provided)       |                         |                                            |
|                                  | Sterling 2004 (WADI/III) Acute/sub-acute      | Mean (SD)degrees/ VAS (pain & disability)                                                                                      |                         |                                            |
|                                  |                                              | • Mild (NDI 15.6) -26.7 (17.7), VAS 1.8 (1.7)                                                                                 |                         |                                            |
|                                  |                                              | • Moderate (NDI 39.5) -31.3 (14.9), VAS 3.0 (1.8)                                                                               |                         |                                            |
|                                  |                                              | • Severe (NDI 69.5) -36.5 (11.8), VAS 4.3 (1.6)                                                                                |                         |                                            |
|                                  |                                              | • Control -21.4 (10.8), VAS 1.7 (1.7)                                                                                        |                         |                                            |
|                                  | Chien 2009 (WADIII)                          | WAD -22.3 (27.4) degrees VAS 2.4 (2.3)                                                                                         |                         |                                            |
|                                  |                                              | Control -11 (5.9), VAS 0.7 (1.1)                                                                                            |                         |                                            |

BPI: brachial plexus irritation, BPPT: brachial plexus provocation test, NDI: Neck Disability Index, VAS: visual analogue scale, ROM: range of movement, S-LLANS: short version Leeds Assessment of Neuropathic Symptoms and Signs

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Individuals with mild, moderate/severe presentations all share comparative levels of sternocleidomastoid activation in the acute [56] and chronic phases [12].

**Myofascial pain and trigger points.** Myofascial trigger points are highly prevalent in WAD with estimates ranging between 48–64% [16, 37, 40]. Muscles that have been investigated include the middle/lower trapezius [16], scaleneus medius [40, 41] and sternocleidomastoid [37, 40, 41], all with similar prevalence levels. Findings suggest that latent trigger points
Table 8. Muscle dysfunction (muscle activation, pain and trigger points).

| Outcome                        | Studies                              | Findings                                                                 | Grade                              | Overall GRADE                       |
|--------------------------------|--------------------------------------|--------------------------------------------------------------------------|------------------------------------|-------------------------------------|
| Muscle activation: all muscles- (n = 220) | Klein 2001 - no change               |                                                                          | 4 case control, 1 single case study | Very low—due to risk or bias, precision, consistency, directness |
|                                | Sterling 2003a SCM (CCFT)            | Recovered 29(4), Mild 27(3), Moderate/severe 40(4), Control 16(3)       |                                    |                                     |
|                                | Sterling 2004 (acute) SCM (CCFT)     | Recovered 29(4), Mild 27(3), Moderate/severe 40(4), Control 16(3)       |                                    |                                     |
|                                | Sterling 2003a SCM (CCFT)            | Control 13(3), Mild 32 (3), Mod 29(4), Severe 47(4)                     |                                    |                                     |
|                                | Sterling 2004 SCM (CCFT)             | Control 13 (3), Mild 32 (3), Mod 29 (4), Severe 47 (4)                  |                                    |                                     |
|                                | Omar 2007 - Weak mid/lower trapezius |                                                                          |                                    |                                     |
|                                | Helgadottir 2011b - serratus anterior delayed onset, mid/low trapezius unchanged |                                                                          |                                    |                                     |
| Muscle activation: all muscle- Acute/sub-acute (n = 146) | Sterling 2003a SCM (CCFT) | Recovered 29 (4), Mild 27 (3), Moderate/severe 40 (4), Control 16 (3) | 2 case control | Very low—due to risk of bias |
|                                | Sterling 2004 SCM (CCFT)             | Control 13 (3), Mild 32 (3), Mod 29 (4), Severe 47 (4)                  |                                    |                                     |
| Muscle activation: all muscles- Chronic WAD (n = 73) | Klein 2001 - no change               |                                                                          | 2 case control, 1 single case study | Very low—due to risk or bias, precision, consistency and directness |
|                                | Omar 2007 - Weak mid/lower trapezius |                                                                          |                                    |                                     |
|                                | Helgadottir 2011b - serratus anterior delayed onset, mid and lower trapezius unchanged |                                                                          |                                    |                                     |
| Muscle activation: SCM (All stages) (n = 192) | Klein 2001 - no change               |                                                                          | 3 case control | Very low—due to risk or bias, precision, consistency and directness |
|                                | Sterling 2003a SCM (CCFT)            | Recovered 29 (4), Mild 27 (3), Moderate/severe 40 (4)                   |                                    |                                     |
|                                | Sterling 2004 SCM (CCFT)             | Control 13 (3), Mild 32 (3), Mod 29 (4), Severe 47 (4)                  |                                    |                                     |
| Muscle activation: SCM- Sub-acute WAD II/III (n = 66) | Sterling 2003a SCM (CCFT) | Recovered 29 (4), Mild 27 (3), Moderate/severe 40 (4), Control 16 (3) | 1 case control | Very low—due to risk of bias |
| Muscle activation: SCM-Chronic WAD II/III (n = 126) | Klein 2001 - no change               |                                                                          | 2 case control | Very low—due to risk or bias, precision, consistency |
|                                | Sterling 2004 SCM (CCFT)             | Control 13 (3), Mild 32 (3), Mod 29 (4), Severe 47 (4)                  |                                    |                                     |
| Myofascial pain and trigger points: all muscles -Sub-acute WADII (n = 20) | Fernandez-de-las-Perez 2012 Number of TPs | WAD Scalene: Active R6, L4; Latent R9, L10; No R5, L6 | 1 case control | Very low—due to risk of bias |
|                                |                                      | Control Scalene: Active R0, L0; Latent R2, L4; No R18, L16              |                                    |                                     |
|                                |                                      | WAD SCM: Active R1, L6; Latent R12, L9; No R7, L5                        |                                    |                                     |
|                                |                                      | Control SCM: Active R0, L0; Latent R4, L5; No R6, L15                   |                                    |                                     |
are more prevalent in sub-acute WADII [41] whereas in chronic WAD there is a higher prevalence of active trigger points [37]. It should however be noted that the sample of chronic WAD comprised both WADII and III, so perhaps severity could partly explain the differences seen. Likewise, age may account for some of the differences given the sub-acute sample was 28.7 years [41] compared 41.6 years in the chronic WAD group [37].

**Discussion**

**Summary of evidence**

This is the first methodologically rigorous systematic review investigating thoracic dysfunction in whiplash associated disorders. From a comprehensive search, 38 studies were included and evaluated as part of the review. Many studies were at risk of bias, primarily due to poor reporting with most studies published prior to the introduction of the STROBE reporting guidelines...
for observational studies. Notwithstanding the low quality of the evidence, there is unequivocal evidence of thoracic dysfunction in WAD.

**Pain.** Although there is a high prevalence of acute and chronic pain experienced in the thoracic spine region following injury, distinguishing the interplay of pain mechanisms is however challenging. Whilst we know peripheral and central sensitisation begin immediately following injury [64], it is plausible that damage to thoracic musculoskeletal tissues contributes to the relatively high prevalence of pain reported in the acute/sub-acute stages from peripheral nociceptor stimuli [11, 14, 17, 43, 52]. Relatively few studies in this review reported perceived pain levels e.g. VAS, making it difficult to consider an association between injury severity and tissue damage. Although reviewed in detail by Van Oosterwijck et al, [64] the current review found just one study reporting thoracic pain specifically associated with central sensitisation, with allodynia reported in 71% of individuals with CWADI/II [33], arguably contributing to the lack of consistency with findings for chronic WAD where differing pain mechanisms may co-exist. Likewise distinguishing local from referred pain is challenging where injury in the cervical spine may refer pain caudally to the upper and mid thoracic region [65]. Unlike the thoracic spine, reported chest pain prevalence was relatively low, perhaps more closely associated with severe injuries, including fractures, which were excluded from this review. Future studies should, in addition to using the QTF Classification, include self-reported pain severity for each anatomical region.

**Thoracic posture and mobility.** With limited very low quality evidence and relative to the cervical spine, there is a paucity of research investigating thoracic posture and mobility in WAD [44, 45, 48, 61]. This may be explained with priority being given to areas with most severe pain, with the cervical spine and associated tissues being most vulnerable to stress and damage compared to the relatively stable and stiff thoracic spine [21], arguably enhanced with the mandatory use of seatbelts offering additional stability. However, considering the effect of a forceful injury on posterior structures, and neck stiffness being a hallmark of chronic WAD further research is required, specifically to investigate thoracic posture, mobility and muscle stiffness in WAD, all of which may offer new directions for research into management of WAD.

**Thoracic outlet syndrome.** Although this review suggests a relatively high prevalence of thoracic outlet syndrome, the quality of evidence is very low and derived from relatively older studies, including two studies from the same group of authors [35, 36]. Whilst the mechanism of injury and resultant strain on the scalene triangle in WAD would, in theory, place the thoracic outlet at risk of injury, this does needs to be investigated further. Likewise as a ‘syndrome’, this does not provide primary evidence of a primary structural dysfunction; it merely provides evidence of a dysfunction which, in turn, could be neurogenic, myogenic, vasculogenic in nature. Perhaps, in the absence of evidence of thoracic outlet syndrome in acute WAD, this condition is secondary to the consequences of whiplash, altered posture, changes in muscle behaviour etc. [66]. Future studies should use robust observational study designs and include valid assessment techniques to diagnose thoracic outlet syndrome.

**Brachial plexus.** There is considerable evidence of brachial plexus dysfunction in both acute/sub-acute and chronic WAD from research investigating the brachial plexus provocation test. Although coming from a relatively small group of researchers, the evidence supports further investigation. Future research could usefully consider the relationship of brachial plexus dysfunction to other musculoskeletal changes in the cervical and thoracic spine following a whiplash injury, but also approaches to managing this; a notable gap within the whiplash management evidence [9, 10, 66]. Although inclusion of the brachial plexus in this review may at first appear tenuous, with contributions from the level of T1 and its relationship to the thoracic outlet, its inclusion provides good evidence to further explore this anatomically and
functionally challenging cervico-thoracic-supraclavicular region; a transitional zone between the stable/stiff thoracic spine and relatively mobile cervical spine.

**Muscle activation.** There is unequivocal evidence of altered function of muscles following whiplash injury [66], however this evidence is largely limited to cervical muscles, with this review identifying just three muscles with insertions to the thoracic region, sternocleidomastoïd [12, 49, 56]; serratus anterior [45]; middle and lower fibres of trapezius [45, 54]. Although it is difficult to derive meaningful conclusions with so few muscles investigated and the quality of the evidence, the observed positive relationship between sternocleidomastoïd activation and pain severity, and evidence across all stages post injury [12, 49, 56] supports the need for further research into altered activation of cervico-thoracic and thoracic muscles, ideally involving functional spinal movements; something that is now feasible with advances in technology, including high density EMG.

**Myofascial pain and trigger points.** This review has identified that myofascial trigger points are highly prevalent in WAD [16, 37, 40], although again from very low quality evidence and limited to a small number of muscles; middle/lower trapezius [16], scaleneus medius [40, 41] and sternocleidomastoïd [37, 40, 41]. Nonetheless all muscles have similar prevalence levels of trigger points, with a higher prevalence of latent trigger points in sub-acute WAD [41] and active trigger points in chronic WAD [37]. With evidence of trigger points across all muscles and across the stages and severity of presentations, research is now required to explore other muscles in the thoracic region and better understand the development of pain, and persistent pain seen in chronic WAD, perhaps with longitudinal studies. Notwithstanding the quality, evidence was found of myofascial-entheseal dysfunction [16], a relatively new clinical entity and arguably similar to insertional tendinopathies. With rapid advances in our understanding of injury induced tendinopathies in the lower limb, this does offer new insights to possible muscle pathologies which may contribute to persistent pain and disability seen in WAD.

This review provides unequivocal evidence of thoracic dysfunction in WAD, albeit from evidence of low/very low quality. The findings do support a more extensive clinical evaluation of patients following a whiplash injury and the need for more methodologically robust observational studies to further characterise thoracic dysfunction in WAD across stages of the condition and levels of severity. Knowledge and understanding of thoracic dysfunction, where anatomical and biomechanical relationships with the cervical spine exist, offers novel directions for research into management of this disabling condition.

Research into WAD management has been, and continues to be primarily focused on managing cervical spine dysfunction, with interventions such as manual therapy, exercise etc. targeting the cervical spine [66], and targeting the psychological impact of a whiplash injury [66]. With inconclusive evidence of the therapeutic value of the above [67] it is perhaps time to consider new directions for research.

Whilst exercise as part of multimodal packages of care is recommended in the management of acute and chronic WAD [66, 68], the range of approaches available are considerable e.g. graded functional exercise, postural exercises, and strengthening and motor control exercises etc. [66]. The authors are not however aware of any recommendations or research specifically supporting the inclusion of thoracic spine exercises, although these could reasonably be incorporated within functional exercise programmes. With at best short term modest improvements in current exercise interventions [9, 10] and some evidence of some therapeutic value of thoracic spine manipulation in WAD [69] further research to investigate interventions targeting the thoracic spine and related dysfunction is justified.

It has not until recent years that the thoracic spine, coined the ‘Cinderella’ of the spine [21], has started to receive more research interest. This has been attributed partly to the relatively
lower prevalence of symptoms than the cervical and lumbar spine more generally, but also due
to the lack of affordable, non-invasive and valid measurement tools to evaluate motion in this
anatomically complex and relatively stiff spinal region [21]. With the development of new
measurement approaches for thoracic posture and mobility [63, 70, 71] we now have tools to
support research of thoracic posture and mobility in the thoracic spine region in painful neck
disorders.

**Strengths and limitations of this review**
This review is rigorous and original, with a design and focus on the thoracic spine region
using a pre-defined rigorous and published protocol with subject and methodological experts
contributing to the evaluation. The key limitation of the review is lack of high quality evidence
and compounding this was that few authors responded to requests for additional information
or data.

**Conclusions**
This first and rigorous systematic review found considerable evidence of thoracic pain and
dysfunction in patients at all stages following whiplash injury. Notwithstanding the low/very
low level of evidence, our findings do support a more extensive clinical evaluation of patients
presenting with WAD. Key findings include 1) a high prevalence of thoracic spine pain, with
the highest levels of pain immediately following injury and in more severe presentations 2) evi-
dence of muscle dysfunction (delayed onset or heightened levels of activity) in a limited num-
ber of muscles 3) evidence of thoracic outlet syndrome and brachial plexus involvement 4)
inconclusive/limited evidence of postural changes and effect on thoracic spinal mobility. Addi-
tional high quality research is required to further characterise dysfunction across other struc-
tures in the thoracic region, including but not limited to the thoracic spine (mobility and
posture) and thoracic muscles (stiffness, activation patterns). In turn this may inform the
design of clinical trials targeting such dysfunction.

**Supporting information**
S1 Table. PRISMA 2009 checklist.
(DOC)
S2 Table. Medline search.
(DOCX)
S3 Table. Excluded papers and reasons.
(DOCX)

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