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Review Article

Whiplash Injuries: A Systemic Review

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Abstract

Whiplash injuries or the group of whiplash-associated disorder (WAD) occur when there is shifting and movement of energy, during a crash or collision, from acceleration-deceleration mechanism transferred to the neck region. WAD is characterized by excessive extension-flexion movements, and/or excessive side bending of the head and neck, beyond the normal and regular range of motion.

Although motor vehicle collisions are the majority of trauma responsible for WAD, other causes also include contact sports injuries, falls, physical and domestic abuse, and other types of traumas.

The clinical picture and presentation are variable. In general, this includes neck pain, decreased range of motion of neck, headaches, arm or arms numbness, and other related symptoms and signs that depend on the extent of the insult. This possibly may include consequences of fractures, joint dislocations, and even traumatic brain injuries/post-concussional syndrome, with its subsequent clinical outcomes.

The trauma associated with WAD outcome can result in acute and chronic pain syndromes, functionality limitations and restrictions, psychological and psychosocial ramifications, financial crisis, unemployment, and in cases, prolonged disability. This causes a significant economic burden on country.

This review manuscript will review the latest in WAD etiologies, biomechanics, diagnosis, management, and prognosis. We base out review on relevant databases such as PubMed, Ovid-Medline, Embase, Web of Science, NIH website, Google Scholar, and the Cochrane Library. No Institutional Review Board permission was obtained since this manuscript does not directly involve animals or humans.

Keywords: Whiplash; Whiplash-Associated Disorder; Neck Pain; Chronic Neck Pain; Motor Vehicle Collision; Chronic Pain Syndrome; Chronic Pain; Neck Trauma

Introduction

According to a study published in 2015, based on statistics for the year of 2010, the U.S. Department of Transportation, National Highway Traffic Safety Administration reports there were "32,999 people killed, 3.9 million were injured, and 24 million vehicles were damaged in motor vehicle crashes in the United States". Studying the economic burden amounted to "$242 billion...this represents the equivalent of nearly $784 for each of the 308.7 million people living in the United States, and 1.6 percent of the $14.96 trillion real U.S. Gross Domestic Product for 2010. These figures include both police-reported and unreported crashes" [1].

For example, in the State of Arizona alone, with a population of about 7.44 million and considered to be the 14th most populous in the United States [2], and according to a study published in 2021 [3], there were a total of 121,345 motor vehicle crashes, of which 1063 were fatal, with 35,203 injuries [3]. This represents 22.45% increase compared to the year of 2020 [3].

With these statistics in mind, there is no doubt that collisions are frequent and health care providers are faced with a plethora of clinical challenges related to collisions, including WAD.

It is interesting to notate that in the early medical reports, whiplash injuries were referred to as 'railway spine' [4]. This term was used in the 19th century to describe the pain and other symptoms related to railway passengers and personnel reported following minor railway crashes [4].

In 1928, Harold Crowe was the first to use the term whiplash to describe 8 types of injuries to the neck associated with car collisions [5].

In 1955, it was reported that even motor vehicle collisions at the speed of 20km/hour can result in injuries to the head and neck and can cause symptoms [6].

Epidemiology

Whiplash-associated disorder (WAD) occur when there is shifting and movement of energy, during a crash or collision, from acceleration-deceleration mechanism transferred to the neck region. With this excessive extension-flexion movements, and/or excessive side bending of the head and neck, beyond the normal and regular range of motion, results at least cervical sprain or strain, if not in more serious injuries such as Grade 1 or more stages of spondylolisthesis, disk herniations, and extrusion, and other more severe pathology.

WAD result in significant economic burden and chronic disability [7]. Depending on the reporting country, WAD varies in incidence between 16 and 200 per 100,000 [8]. It has also been reported that about 50% of WAD patients will complain of neck pain symptoms a year post-collision [7,9].

Gender differences in WAD

Overall, a study has shown that women are seeking care more often than men for WAD [10]. Similarly, in that study by Holm et al, there has been an increase in visits to emergency rooms due to whip- lash trauma in the western world over the past 30 years [10].

The same study demonstrated that the newer designs of headrests and vehicle seats curb whiplash injuries during rear-end motor vehicle collisions are more beneficial, especially to women [10].

A study conducted on 90 patients, out of Sweden, published in 2001, showed that women were found to have more symptoms related to whiplash injuries than men [11].

Another study out of Sweden published in 2017, sought to investigate any gender differences in seeking care behavior regarding whiplash trauma [12]. The conclusion demonstrated that "women sought healthcare later than men did, women sought care at primary care facilities slightly more often than men who more often went directly to a hospital. Nothing indicated that women had a milder injury than men did" [12].

In an interesting study for the effectiveness for males and females of cars fitted with whiplash protection systems, published in 2010 at the International Research Counsel of Biomechanics of Injury [13], it was found that women had approximately 50% higher risk of reporting an injury in rear-end crashes compared to men. Women also had a double risk of symptoms lasting longer than one month compared to men, and a double risk of injuries leading to permanent medical impairment. Whiplash systems were found to have a significantly higher "protective" effect for men than for women. For women the reduction was approximately 45%, and for men approximately 60% [13].

Clinical presentations of WAD

As is the case with any injury, the presentation of complaints can vary significantly between individuals following whiplash. But there are certain clinical presenting features shared by many patients. Among others, these include neck pain, headaches, dizziness, and spasms. For the sake of simplicity, and to focus on the main topic of whiplash, we will only elaborate on neck pain in this manuscript.

Neck Pain: A main clinical presentation

Deans., *et al.* [14]. estimated that neck pain occurred in 65% of patients within 6 hours, 93% within 24 hours, and 100% within 72 hours after neck injury. There are many variations depending on many factors including the extent of neck injury, direction, mechanism, force, and acceleration.

Tanaka., *et al.* [15]. explained that typically pain is not as severe and take a 'time lag' to develop. He used a reference in Japanese and had an explanation for this his time lag secondary to "synovitis of the facet joints, where the synovial tissue involved in the facet joint has been damaged by non-physiological behavior during a collision, which may induce synovitis of the facet joint after several hours, leading to neck pain and a limited range of motion" [15].

Although many patients recover after treatment, Benoist., *et al.* [16]. demonstrated that "neck pain and headaches continue for several years in 20-40% of patients, with 3-4% of patients unable to return to work" [16].

Patients with WAD examined within 3 days after the trauma had a significant increase in pro-inflammatory tumor necrosis factor (TNF)-α and interleukin (IL)-6 and of anti-inflammatory IL-10 [17]. These normalized in the following 24 hours [17].

Additional studies published in 2002 [18], studying 3 research data in depth, including a study that used surface cryo-planing microtomy autopsy technique of fatal road collisions and a control group, indicated that subtle lesions in the cervical intervertebral disc and zygapophyseal joints could be clinically relevant in WAD and that a very high proportion of these lesions were not seen on postmortem radiological studies [18,19].

One study demonstrated that in contrast to injuries to ligaments, facet joints, and discs, muscle injuries would normally heal in a few weeks and not cause chronic pain [20].

Controlled diagnostic blocks of cervical zygapophyseal joints of patients with chronic WAD have shown that the facet joints can be the source of pain [21,22]. The results of these studies might indicate that these joints were injured in the trauma situation. The reported prevalence was between 54% and 60% from their consecutive patients with chronic WAD [21,22]. One of the studies was placebo-controlled prevalence study [22].

Radanov., *et al.* [23]. reported that 97% of chronic traumatic cervical syndrome patients have neck pain, while Al-Khazali., *et al*. [24], in a meta-analysis study, reported that a pooled relative frequency of neck pain was 84% [24]. At 12 months after injury, 38% of patients with whiplash still experienced neck pain, while 38% of whiplash patients reported headache a year after the injury [24].

In addition to neck pain, many other symptoms and signs can be found in whiplash injuries. These include headaches, radicular symptoms, stiffness in the neck and interscapular region headaches occipital neuralgia, limitation in flexion and/or extension, loss of concentration, paresthesia in the arms or hands, vertigo, dizziness, general tiredness, short-term memory, personality changes, disturbances with word finding and, neurological deficit [25].

Classifications of WAD

To date, several clinical classifications of WAD are available. The most frequently used, and that the authors use, is based on the scientific monograph of the Quebec Task Force (QTF) on Whiplash-Associated Disorders [26]. In the rest of this manuscript, we will only consider QTF to talk about the rest of the manuscript main topics.

Quebec task force classification

In this rather simple classification, Grades 0, I, and II correspond to the common term of whiplash injury, whereas grades III and IV are classified as traumatic cervical spinal cord injury [26] (Table 1).

Grade complaint

- **Grade 0:** No complaint about neck pain. No physical signs
- **Grade I:** Neck complaint of pain, stiffness, or tenderness No physical signs
- **Grade II:** Neck complaint Musculoskeletal signs including Decreased range of movement. Point tenderness.
- **Grade III:** Neck complaint Musculoskeletal signs Neurological signs including Decreased or absent deep tendon reflexes Muscle weakness. Sensory deficits
- **Grade IV:** Neck complaint and fracture or dislocation.

Radanov whiplash classification

Radanov and co-workers formulated this classification based on subjective complaints and formal testing of self-estimated cognitive impairment, divided attention, and speed of information processing [27]. The results of this study resulted in 2 main syndromes.

- The "cervicoencephalic syndrome" characterized by headache, fatigue, dizziness, poor concentration, disturbed accommodation, and impaired adaptation to light intensity [27].
- The "lower cervical spine syndrome" which is accompanied by cervical and cervicobrachial pain[27]. Radanov., *et al*. concluded that those suffering from "cervicoencephalic syndrome" had significantly poorer results when tested for divided attention [27].

Gerdle whiplash classification

Gerdle and Co-workers [28] out of Sweden, formulated yet another classification. The classification of the injuries is based on

an anatomical axis and a time axis (see Table II). It reportedly has advantages especially when combined with the QTF classification [29].

Anatomic axis description

- **Category A:** Head, neck, and shoulder
- **Category B:** Head, neck, shoulder, and arm (Pain, numbness, motor weakness)
- **Category C:** Head, neck, shoulder, and CNS (dizziness, visual changes, sensitivity to light and sound, stress intolerance, cognitive problems)
- **Category D:** Head, neck, shoulder, arm, and CNS.

Time axis

Number of weeks with complaints: Acute ≤ 12 weeks, chronic ≥12 weeks

Pathology and the biomechanics of whiplash injuries

Pathology of WAD

Many studies performed on post-mortem motor vehicle collision victims demonstrated that most soft-tissue lesions observed in autopsy studies were not visible on postmortem radiographs [30]. Studies also showed that even magnetic resonance imaging (MRI) significantly underestimates the extent of injuries found at surgery to alleviate the pain [31]. Most patients with severe persisting radiating pain had large disc protrusions on MRI that were confirmed as herniations at surgery [31].

As early as 1964, Mcnab used a sled-seat, accelerated backwards to impact, to produce neck hyper-extension injuries in monkeys [32]. It was found that "anterior distraction caused tears of longus colli with formation of retro-pharyngeal hematomas, tears of the anterior longitudinal ligament, and avulsion of the disc from the vertebral body. Posterior compression caused facet joint hemarthroses. The disc and ligament injuries were among the most reproducible lesions." [33,34].

Taylor and his associate studied 16 cervical spines from fatal motor-vehicle collisions. They found posterior disc herniations and hemarthroses in facet joints, as compared to 16 controls that did not show these lesions [35].

James Taylor, MD, PhD published significant findings related to upper cervical soft tissue injuries [34]. His findings were extremely significant and can clinically explain many of the patients' complaints that we otherwise ignore as having 'psychological issues'. Because of the importance and accuracy of the findings, paraphrasing his conclusions, he states: "the most common injury was bruising of the intra-articular synovial folds of the lateral atlanto-axial joints with or without hemarthrosis… Anterior and posterior gaps are filled by large vascular synovial folds. In normal movements these move out of the way of the closing articular surfaces, but in crashes lasting a few milliseconds, the synovial folds are exposed to being nipped, bruised, or ruptured. Posterior synovial fold bruises were often associated with a hematoma located behind the joint and around the dorsal root ganglion of C2. This ganglion is surrounded by thin-walled veins in a small compartment deep to the obliquus capitis inferior. The veins may be damaged, and the hematoma may track along the greater occipital nerve as it arches below the inferior oblique muscle. Injuries to the C1-2 synovial folds were seen in 60% of the cervical spine, usually independent of any fracture or dislocation" [34]. He also added that "the cervical spine is more vulnerable to extension due to the paucity of anterior muscles... Cervical disc, ligamentous, and zygapophyseal joint injuries were four times more frequent than vertebral fractures. Both extension and side flexion injuries may injure cervical dorsal root ganglia." [34].

Biomechanics of WAD

Based on our extensive review of the published data, WAD injuries are essentially soft tissue injuries to the neck region and cervical facet joints. Based on this finding, the WAD main presentation will encompass neck pain, neck stiffness, decreased range of motion, interscapular pain and spasms, and neck spasms, with or without shoulder involvement [36].

Chen et al published a landmark biomechanical interpretation of the findings associated with whiplash injury [36].

In rodents, experimental biomechanical studies have shown that strains of the cervical facet capsules are the responsible mechanism of whiplash symptoms [36].

In humans, based on cadaver and volunteer kinematical studies, there were 3 different potential periods for genesis of neck injury and pain. The first stage is 'flexural deformation'. This is seen in association with loss of cervical lordosis. The second is the S-shaped curving in the lower cervical vertebrae, that extends gradually and causes the upper cervical vertebrae to extend at a later stage. The final stage is when the entire neck is extended [36,38]. We will elaborate in further detail about these stages below.

Chen., *et al*. [36]. concluded that "injuries to the cervical facet capsules is a major source of post-crash pain, secondary to joint capsules receptors firing" [36].

In a Swedish study, Krafft., *et al.* [37]. concluded that patients who sustained whiplash injuries experienced low-to-moderate speed rear impacts [37]. He also concluded that rear impact collisions caused twice as much neck pain compared to head-on or "frontal" collisions [37].

Clinically, based on published data, Chen., *et al*. [36]., described three major structures that are affected the most in whiplash injuries: cervical facet joints, intervertebral disks, and the upper cervical ligaments [36]. In his clinical opinion, other structures were less frequently involved. He elucidated more on detailed cervical facet capsular joints and enumerated ligament tears cartilage damage, and contusion of the intra-articular meniscus with joint hemorrhage, and possibly microfractures are the main causes of cervical facetogenic pain [36]. As far has intervertebral disks, he enumerated annular fibrosis fissures and tears, disk protrusions, and avulsions of the vertebral endplates [36]. Regarding cervical ligaments, he concluded that tears of the Anterior Longitudinal Ligaments (ALL) is the culprit [36].

Biomechanics in cadaveric kinematics

Luan and his team [38] conducted a superb study on cadavers to study the impact of rear-end collisions on cadavers. He divided the findings into 3 main stages.

- **Stage I, (0-100 millisecond (ms) after onset of impact):** There is flexural deformation of the cervical spine, with loss of lordosis. At 20 ms, the initial lordosis becomes straight. After 50 ms, both upper and lower cervical vertebrae go in flexion. The shear force starts in lower then travels to upper cervical spine. Axial foe changes from compressive to tensile at about 60 ms [38].
- **Stage II, (100 to 130 ms after impact):** Cervical spine initially assumes S-shaped curve in lower that travels to upper cervical spine. Shear force acts at all levels with tensile axial force [38].
- **Stage III, (after 130 ms from impact):** There is extension of entire cervical spine. Shear and tensile force continue to impact all levels. There is posterior more than anterior cervical facet joint compressions, causing the capsules to compress and slide along the joint [38].

Biomechanics and kinematics in human volunteers

Kaneoka and his colleagues out of Japan, conducted a brilliant study of 10 healthy volunteers. They were all seated on a sled and subjected to rear-impact collision only at the speed of 8km/hour. This was used to study the dynamics and motion of the head-neck-torso, and cervical spine motion [39]. He used actual live high-speed radiography with surface EMG monitoring of the cervical paravertebral and sternocleidomastoid muscles. Each of the cervical spine vertebrae was monitored and analyzed [39]. At the conclusion of the study, there were 4 phases extrapolated as follows.

- **Phase I:** At 0-40 ms, no cervical spine muscles were obtained [39].
- **Phase II:** At 40-100 ms, the cervical spine vertebrae assumed S-shape with upper in flexion and lower in extension. No cervical spine muscles were obtained [39].
- **Phase III:** At 100-160 ms, the axial force on the neck reaches 120 ms. EMG of the sternocleidomastoid discharged at 150 ms [39].
- **Phase IV:** At 15-200 ms, there was decrease in shear axial forces in the neck. EMG discharged at 220 ms [39].

Based on the findings of this data, and with this level of low-speed testing, Kaneoka and his team concluded there were 4 potential phases that can cause neck injury during rear-impact collisions: A: Early in the impact, even during head retraction period, there is S-curving of the cervical spine. B: Injury due to head restraint, if poorly positioned in respect to the head and neck and timing of the collision. C: Injury due to hyperextension for a severe impact with poorly fitted head restraint or without presence of head restraint. D: Rebound into the seatbelt [36].

Biomechanics of the cervical facet joints

It is no secret that spine-practicing clinicians are aware of the active role of facetogenic pain in whiplash injuries. Nevertheless, there was a need for basic and clinical research studies to establish this as the main mechanism of injury.

In 1999, Kaneoka., *et al*. [40] studied the facet joint motion during human volunteer studies of whiplash injuries and established differential kinematics between upper and lower cervical segments of the cervical spine [40].

Panjabi., *et al*. [41] went further and studied the quantification of C6-7 facet joint ligament strain and displacement using trans-

ducers inserted into the facet articulations. The team found that in normal and regular flexion/extension ROM, the capsular strain is 6.25% ± 5.6%. This was different in cadaveric acceleration of head and neck at 6.5g, where the C6-7 strain reached 29.5% ± 25.7%. These findings suggested that capsular facet joint elongations as potential mechanism of injury [41].

Similar studies conducted by Pearson., *et al*. [42], at 8g acceleration showed that the maximal strain produced by facet sliding and separation at C6-7 were 39.9% ± 26.3% [42].

Finally, in a study of mechanical evidence of cervical facet capsule injury during whiplash in cadavers, Siegmund., *et al.* [43] used combined shear compression and extension loading and demonstrated that the likelihood of subcatastrophic failures in combined shear loading during whiplash kinematics in the facet capsule sustaining strains is of 35% ± 21.0% [43].

Mechanisms of injury of cervical spine during whiplash injury

While reviewing the early published studies related to whiplash injuries, many of them pointed to hyperextension as the main mechanism of injury in whiplash. Since then, many potential mechanisms have been suggested. We will review these in this section.

Muscle strains and injuries

As aforementioned, during phase III of whiplash injury, at 100-160 ms, the axial force on the neck reaches 120 ms. EMG of the sternocleidomastoid discharges at 150 ms [39]. One theory is that during this hyperextension movement of the cervical spine, the anterior cervical muscles, mainly the sternocleidomastoid contracts and this is called eccentric contraction [39]. This is caused by stimulation of muscle spindles in the flexor muscles that are being stretched [39].

The theory of potentially injured musculotendinous straining of the sternocleidomastoid muscles during whiplash injury was also supported by other studies [44].

A second muscle injury theory is because extensor muscles are potentially injured during rebound of the head and neck as they undergo eccentric concentration during rebound of impact from phase IV [39]. At phase IV, at 15-200 ms, there is decrease in shear axial forces in the neck. EMG discharges at 220 ms [39].

Other studies have also supported the occurrence of larger strains in the superficial posterior neck muscles such as semispinalis, splenius capitis, and upper trapezii [45].

But regardless of the muscles injured, it is agreed upon those injuries to deeper cervical spine muscles, with higher type I fiber make-up, will require higher magnitude of severity of injury as compared to muscles that are more superficial muscles, such as those with a higher type II muscle fiber distribution [46].

Injuries to the cervical facet joints

This section was covered above under "biomechanics of the cervical facet joint" in depth.

Injuries of the cervical spine ligaments

One of the theories of whiplash mechanism of acute injury is involvement of injuries to the ligaments of the cervical spine [47]. The ligaments involved include the anterior and posterior longitudinal, capsular, interspinous, supraspinous ligaments, middle-third disc, and finally the ligamentum flavum [47]. All whiplash-exposed ligaments, the failure elongation exceeded the average control physiological elongation leading to ligaments, and subsequent cervical spine instability [47]. The altered mechanical properties of these ligaments may cause subfailure injuries of these ligaments and the embedded mechanoreceptors [47]. The decreased ligament strength may potentially lead to altered facet loading capacity causing excessive synovial fold and facet articular cartilage material compression [47]. This potentially may lead to chronic pain and inflammation and even early osteoarthritis [47]. Published in 2006, Panjabi [48] demonstrated that in chronically injured ligaments, corrupted transducer signals from the injured mechanoreceptors may lead to altered muscle responses. This will cause excessive ligament strains and disc and facet loading [48]. This potentially can result and lead to chronic neck pain via inflammation of spinal nerve roots and ganglia [48].

Dorsal root ganglion (DRG) and injuries to the nerve roots

The anatomic location of DRG and nerve roots unfortunately makes them more prone to injuries during rear-ending or lateral bending of the cervical spine during motor vehicle collisions. In a study conducted by Taylor., *et al*. [49], in which his team studied 109 victims of fatal blunt injury, focusing on injuries to the dorsal

root ganglia, and studying the impact on the entire cervical spine, it was found that 44 cases of interstitial hemorrhage into the DRG, sometimes accompanied by neural tissue disruption, visible only on histological study. The intraneural DRG hemorrhage was found in 13.8 per cent of all the injured individuals, but this prevalence rose to 34.5 per cent when considering individuals surviving the injury between 2 h and 7 days [49].

Another study [50] focused on the changes of spinal canal volume in whiplash injuries [50]. It was found that impulsive pressure transients in the venous blood outside the dura mater (DM) and in the cerebrospinal fluid (CSF) inside the DM. This interaction includes two basic mechanisms, i.e., the pulling and pressing effects. In the pulling process, the DRG is stretched towards the spinal canal, and the venous blood is driven into the canal via the foramen, because of negative pressure in the fluids. In contrast, the pressing process is caused by positive pressure leading to compression of the DRG and the outflow of the venous blood from the canal. The largest pressure gradient is observed at the foramen, at the DRG location. The study concluded that the pulling process is most hazardous condition for the DRG [50].

In reviewing the published clinical research data, a study [51] reviewed 54 studies in 390,644 patients suggesting that after whiplash injury, the mean prevalence of nerve pathology identified by clinical neurological examination, the mean prevalence was 13%, and using EMG/NCV, it was an average mean prevalence of 32% [51-53]. On the other hand, the prevalence of neuropathic pain after whiplash injury, determined with questionnaires, ranged from 34% to 75% [51].

Disk displacements and injuries in whiplash

Disk herniations are more likely to occur following a posterolateral direction. This is due to the fact the annulus fibrosus is thinner and lacks the structural support from the posterior longitudinal ligament. Since the disk herniation is close to the traversing cervical nerve root, the herniation that come in contact and compress the cervical root as it exits. This can result in radiculopathy in the corresponding dermatome [54].

Pathophysiologically, a herniated disc is a result of mechanical compression of the nerve by the bulging nucleus pulposus and a local increase in inflammatory cytokines. The mechanical compression may lead to microvascular damage, with either mild compression producing partial obstruction of venous flow triggering local inflammation, or leads to severe compression, that may result in arterial ischemia. Herniated disc material and subsequent nerve involvement may lead to the production of inflammatory cytokines, including IL-1, IL-6, substance P, bradykinin, TNF-alpha, and prostaglandins [55].

A study [56] aimed to study the development of disc pathology and its relationship to clinical findings after whiplash injuries. It included 39 patients with an average age of 32. It found that 33% of patients had disc herniations with medullary or dura impingement over the 2-year follow-up period. At the follow-up examination all patients with medullary impingement still had persistent or increased symptoms, and 11% had no or slight changes on magnetic resonance imaging had persistent symptoms [56].

In one study conducted by Taylor [57], it was found on autopsy performed on cadavers of vehicle collisions sustaining whiplash that the major injuries were confined to one or two levels, most often at C5-6 and C6-7, and the minor injuries were often multilevel and were most seen at C3-4 and C4-5 [57]. In the same cadaveric study [57], the most common disc injuries were found to be rim lesions followed by avulsions, and then followed by disk herniations. Annular disk tears were seen in subjects under 55 years, whereas irregular disc disruption was found in subjects over 55 [57]. When herniations were found contained, there usually was an intact posterior longitudinal ligament. But large herniations impinged upon the dura or spinal cord. Disk pathologies also included annular fragments, central disc material, or part of a cartilage plate torn off the vertebral end plate [57]. When compared to non-trauma controls, none of these findings were present, pointing to trauma related to whiplash injuries [57].

Diagnosis of WAD

Diagnosis of whiplash injuries remains mainly clinical. The authors believe that a thorough and documented mechanism of injury is paramount. In general, diagnosis is established by clinical points and facts gathering, but it is our opinion that it is essential to obtain diagnostic imaging sooner rather than later. The idea is to document, and early on, any early changes in the cervical spine, including the initial straightening of the normal lordotic curve by a series of X-rays that will point to presence of muscle spasms. This

will aid the clinician to take steps to decrease spasms and improve ROM early on. The authors also promote ordering flexion/extension series in case of presence of cervical spondylolisthesis. CT scans or MRIs (depending on patient's choice and possible history of MRI contraindications of any sort), and finally EMG/NCV. MRIs remain essential to diagnose and treat the exact pathology the clinician will address.

Radiological studies

It is important to establish cervical stability and rule out occult cervical spine injuries after whiplash injuries [58]. Many authorities do promote the routine use of X-rays to rule out cervical pathologies [58,59]. Others promote the use of radiographs regardless of the mechanisms when there is "any alteration in level of consciousness, any evidence of trauma to the head or neck ("above the clavicles"), any evidence of intoxication, any distracting painful injury elsewhere, for age greater than 65 years, for high-speed rear-end motor vehicle collision, in presence of focal neurologic symptoms or signs, where active neck rotation cannot be completed in the defined manner, where examination of the neck is unreliable, in presence of altered level of consciousness, or evidence of facial or external head injury" [60].

In general, the cervical spine X-rays should include standard three-part series. These include a lateral view with visualization of the superior part of T-1, an anteroposterior view, and an open-mouth or odontoid. Some centers also recommend performing left and right oblique projections, and yet others include a swimmer's view for better visualization of T-1 [60].

CT scans and MRIs role in whiplash

Many of the patients we see have already sought help at emergency departments where they had CT scan imaging to rule out acute pathologies of the cervical spine. In general, the authors promote the use of MRIs instead of CT scans except if there are contraindications to the use of MRIs such as presence of pacemaker or other contraindications, including lack of patient's consent.

The authors opine that the clinical usefulness of MRI scans in whiplash injuries is essential to verify the integrity of the cervical spine. For example, these include but not limited to edema of soft tissue and muscles, rupture of ligaments, facet joint effusions and hypertrophy, disk pathologies such as bulges, protrusions, herniations, extrusions and sequestration, tonsillar ectopia, annular fibrosis fissures and tears, presence, and degree of foraminal and spinal stenosis, cord compression and edema, and lateral recess stenosis. In addition, MRI will aid in identifying the level and extent of compression factures with or without retropulsion, spondylolysis or spondylolisthesis, and point to the pre-existing pathologies such as degenerative joint disease, and presence of bone spurs and osteophytes.

Electromyography (EMG)/nerve conduction velocity (NCV) in whiplash injuries

The authors' clinical experience dictates promoting the integration of baseline EMG/NCV of the upper extremities as one of the initial available diagnostic tools, to be performed a few weeks after whiplash injuries, regardless of complaints of arm paresthesia or not.

In a study [61] published in 2019, healthy volunteers were subjected to a low-speed sub-injury level of rear impact. EMG measured the muscle activity from relevant muscles during rear-end impacts, it found "significant" activities of the cervical muscles. The sternocleidomastoids, trapezius and erector spinae were activated on average 59 ms, 73 ms and 84 ms after the impact stimulus, respectively, prior to peak head acceleration (113 ms) [61]. Keeping in mind the fact this study from Europe focused on "low-speed" impact and found relevant results. In real life, in the US, the injuries are not selective nor are they all low impact or low-speed.

In a systematic meta-analysis review involving 54 studies and a total of 390,644 patients, it suggested that after whiplash injury, the mean prevalence estimates of nerve pathology in WAD were estimated to be 32% on electrodiagnostic testing [62].

A study conducted by Nederhand and his team [63] concluded there was only a tendency of higher muscle reactivity on EMG in patients with whiplash-associated disorder Grade 2 [63].

Management and treatment of WAD

There are many factors and variables that come to play in the management section. But for the sake of simplicity, we will only enumerate evidence-based management options, and what the authors usually apply in their corresponding practices.

Management of WAD will vary depending on the mechanism

of accident, speed involved extent of injuries, complaint priorities that the patient presents with, and multiple other factors that we can't delve into here. But in general, the authors will divide this management section into medical (medication) management, physiotherapy, chiropractic, acupuncture, massage and myofascial release, and trigger point injections.

Unfortunately, we will not be able to cover the topics of interventional pain procedures, kyphoplasties if needed, and possible surgical options due to manuscript size restrictions.

Medication management

Acetaminophen

This first choice, widely available, non-prescription, over-the-counter medication is highly used all over the world, and depending on geographic location may come in different names such as Acetaminophen, APAP, Paracetamol, or Panadol.

Tylenol is analgesic and anti-pyretic. It is not anti-inflammatory like Non-Steroidal Anti-inflammatory Drugs (NSAIDs) are. It remains the most popular and most widely used medication for pain [64]. Tylenol is considered safe and doesn't have the major side effects that come with NSAIDs, such as renal side effects, gastrointestinal, water retention (and weight gain), cardiovascular side effects/hypertension, cerebrovascular side effects, and asthma/bronchospasm induction and exacerbation. It can be safely used in even in the elderly, the children, and pregnant women. A safe dose is less than 4000 mg per day. Hepatotoxicity is the greatest side effects of Tylenol and the most frequent cause of drug-induced acute liver failure in Western countries [64], especially for those individuals who have predisposing factors for liver injury. However, its precise mechanism remains unclear and no effective cure beyond N-acetylcysteine has been developed. Recent animal and cellular studies have demonstrated that some cellular events, such as c-jun N-terminal kinase (JNK) pathway activation, endoplasmic reticulum (ER) stress, and mitochondrial oxidative stress may play important roles in the development of hepatitis [64].

The exact mechanism of action of Acetaminophen remains unknown, but it theoretically inhibits the cyclooxygenase (COX) pathways in the central nervous system but not peripheral tissues [65-67]. Acetaminophen does not appear to bind to the active site of either the COX-1 or COX-2 enzyme. Instead, it reduces the activity of COX by a different mechanism, likely inhibiting a splice variant of COX-1, also called COX-3, but this has not been confirmed in humans [65].

The authors suggest its regular use in the initial 10 days (500 mg 3-4 times a day), and then after that to take it as needed for pain.

NSAIDs for whiplash

The traditional and "reflex" prescribing of NSAIDs for acute pain has been recently challenged. Prescribing NSAIDs was almost part of any acute or even chronic pain management regimen. Although it is still taking place amongst many clinicians, the new research has shown otherwise [68]. The natural inflammatory response that takes place during whiplash injuries looks beneficial now and curbing that inflammatory response may lead to chronic pain [68].

In a monumental publication, Parisien., *et al.* [68] focused on the immune system using human and animal models. Transcriptomic analysis in immune cells from subjects with low back pain showed that neutrophil activation-dependent inflammatory genes were up-regulated in subjects with resolved pain, whereas no changes were seen in patients with persistent pain. In animals, anti-inflammatory treatments prolonged pain duration and the effect was neutralized by neutrophil administration. Additionally, it was shown that the use of anti-inflammatory drugs was associated with increased risk of persistent chronic pain, suggesting that anti-inflammatory treatments might have negative effects on pain duration [68].

NSAIDs mechanism of action of anti-inflammatory effect is by inhibiting COX, which is the rate-limiting enzyme in prostaglandin synthesis [69]. There are at least two major isoforms of the COX enzyme-COX-1 and COX-2 [69]. Both isoforms catalyze the conversion of the unsaturated fatty acid arachidonic acid into prostaglandin H_2 [69]. This is further modified by tissue-specific isomerases into bioactive lipids called prostanoids. These prostanoids include prostaglandins I_2 (prostacyclin), D_2, E_2, $F_{2\alpha}$, and thromboxane A_2, are mediators of a variety of biological effects [69].

NSAIDs are associated with high prevalence of side effects especially at extended use. The authors suggest use of no more than 3-4 days, and total avoidance in individuals over the age of 60. NSAIDs

lead to the development of hypertension in both normotensive and hypertensive individuals [70]. Their use interferes with the anti-hypertensive medications except for the calcium channel blockers [71]. There is also increased risk of atrial fibrillation or flutter was 40-70% (lowest for non-selective NSAIDs and highest for COX-2 inhibitors) [72]. NSAIDs were also associated with dose-dependent increased prevalence of myocardial infarction, congestive heart failure, cardiovascular thrombosis, transient ischemic attacks, and cerebrovascular accidents [73-78].

A high-quality study on NSAIDs in subacute neck pain on 72 patients found that diclofenac gel used topically was more effective than placebo in reducing pain [78A].

Muscle relaxants

In searching the published clinical studies, authors didn't encounter any published studies related to muscle relaxants use in whiplash injuries. But a systematic review on low back pain found muscle relaxants to be superior to placebo in terms of pain relief but were not free of inhibition of central nervous system [79]. A comprehensive review of about 50 studies investigated the use of muscle relaxants in low back pain and established their effectiveness but only for short term use [80].

In Metanalytical systematic review of efficacy, acceptability, and safety of muscle relaxants for adults with non-specific low back pain, it found that "considerable uncertainty exists about the clinical efficacy and safety of muscle relaxants" [81].

Our own experience promotes the safe use of muscle relaxants in the initial few days, typically the first 3-4 days after whiplash injuries and their use at night rather than daytime to avoid sedation, and lack of productivity.

Steroids use after whiplash injury.

The authors are in favor of the use of oral steroids in form of Methylprednisolone 4 mg tablets in a tapered fashion, for 5 days, and as early as the whiplash occurs, for WAD I-II. We feel this acts as a "pain killer" and restores initially lost range of motion of the cervical spine and promotes early return to work.

In a prospective randomized, double-blind study, the use of high-dose intravenous Methylprednisolone was compared with placebo involving 40 patients who sustained whiplash injuries [82]. The results showed that acute treatment with high-dose Methylprednisolone "may be beneficial in preventing extensive sick leave after whiplash injury" [82].

In another randomized, double-blinded, placebo-controlled trial [83] was conducted on adult patients with neck/shoulder pain for at least 1 month duration, patients were allocated to receive prednisolone 50 mg/day for 5 days that was tapered within the following 5 days, or to receive placebo. All patients also received acetaminophen 325 mg three times a day and ranitidine 150 mg two times a day. Neck disability index and the verbal rating scale were used to evaluate the outcomes [83]. It concluded the prednisolone was "highly effective" in reducing pain in patients with cervical radiculopathy [83].

Physiotherapy, chiropractic, acupuncture, massage, myofascial release for whiplash

Physiotherapy

Manual physiotherapy aims to improve spinal joint motion and restore range of motion. It consists of mobilization and manipulation. Mobilization entails the use of low-grade/velocity, small-amplitude, or large-amplitude passive movement techniques within the patient's range of motion and based on patient's control. Manipulation is defined as a localized high-velocity and low-amplitude force directed at specific cervical or thoracic spinal segments near the end of the patient's range of motion and without their control [84].

A Cochrane review found that both cervical mobilization and manipulation were equally beneficial with moderate-quality evidence in patients with non-specific neck pain. According to this review, thoracic manipulation showed a larger beneficial effect when compared to an inactive treatment (moderate-quality evidence), indicating that thoracic manipulation was more beneficial than cervical manipulations [84,85].

A meta-analysis systematic study [86]. of 21 randomized controlled trials showed inconclusive evidence exists for the effectiveness of physiotherapy management for whiplash associated disorder II. It found potential benefit for improving range of movement

and pain short term through active physiotherapy, and for improving pain through a specific physiotherapy intervention [86].

In conclusion, physiotherapy study guidelines focus on exercise, advice to stay active, return to normal activity, multimodal interventions, and manual therapy [87].

Chiropractic interventions

Chiropractic role is essential in cases of motor vehicle collision. Chiropractors are considered the gate keepers for whiplash injuries and have established and proven themselves as health care providers.

A systematic review of the empirical studies relevant to WAD interventions was conducted and scrutinized for review of the evidence. A total of 27 articles were consistent with specific criteria of WAD intervention were analyzed thoroughly [88]. There was a baseline of evidence that suggests chiropractic care improved cervical range of motion and pain in the management of WAD [88].

In a double-blind randomized controlled trial involving 105 patients, it was found that spinal manipulation of the cervical spine increased active range of motion, in a consistent and statistically significant manner [89].

In another study [90], the goal was to study the immediate sensorimotor neurophysiological effects of cervical spine manipulation after using somatosensory evoked potentials (SSEP). It was found that spinal manipulation of dysfunctional cervical joints led to transient cortical plastic changes, as seen by attenuation of cortical somatosensory evoked responses [90]. The results suggested that cervical spine manipulation may alter cortical somatosensory processing and sensorimotor integration [90]. These findings translated the mechanism for the effective relief of pain and restoration of functional ability following spinal manipulations [90].

Acupuncture for whiplash injuries

In a Korean randomized controlled trial [91], involving 97 patients, the study aimed to examine the effects and safety of motion style acupuncture treatment (MSAT; a combination of acupuncture and Doin therapy) on pain reduction and functional improvement in patients with whiplash injuries. The patients were randomized MSAT and integrative Korean medicine (IKM) and compared with controls for 90 days. It was found that the rate of recovery of neck pain was significantly faster in the MSAT than in the control group. The study concluded that IKM treatment combined with MSAT was more effective in reducing the pain and improving the range of motion in patients with WAD [91].

A study [92] that looked at total of 124 patients between 18 and 65 years with WAD were randomly allocated to real or simulated electroacupuncture treatment for 12 sessions during a 6-week period [92]. Real electroacupuncture was associated with a significant reduction in pain intensity over at least 6 months [92].

In another study [93] involving 87 patients involved in whiplash injuries grade 1 to 3, each received acupuncture received 3 sessions, involving needling of traditional acupuncture points and/or myofascial trigger points of the neck and upper/lower back. The pain significantly decreased and there was improvement in indicators such as neck disability index, Oswestry low back pain scale and Quick disabilities of the arm, shoulder, and hand [93]. Most of the patients were able to return to full-work duties following treatments. The study concluded acupuncture appears to be an effective clinical treatment for WAD patients [93].

Massage and myofascial release in WAD

A study [94] published in 2016 reviewed and included randomized controlled trials, cohort studies, and case-control studies comparing manual therapies, passive physical modalities, massage, myofascial release, or acupuncture with other interventions, placebo, or sham, or no intervention [94]. The purpose aimed to update the findings of the Neck Pain Task Force on the effectiveness of these modalities in WAD [94]. The findings suggest that mobilization, manipulation, and clinical massage are effective interventions for the management of neck pain [94].

Another research study [95] sought to work on guidelines for neck pain linked to WAD. It reviewed multiple randomized controlled trials and concluded, that among other modalities, massage and myofascial release were effective treatment strategy for both recent-onset and persistent neck pain related to whiplash injuries [95].

More research clinical data [96] showed that people who were

treated with this manual approach had a greater improvement in cervical range of motion, and greater scores on visual analogue scales, than those treated with conventional physical therapy [96].

Myofascial trigger point injections for whiplash injuries

The authors strongly promote the use of a series of 3-5 trigger point injections (TPI) in whiplash injury patients, regardless of duration that passed since the collision took place. We suggest using plain sterile, bacteriostatic normal saline solution with or without a local anesthetic, preferably 0.5% or 1% Lidocaine. Local anesthetics especially Bupivacaine, followed by Lidocaine may cause some degree of dizziness, and may trigger vasovagal reactions, in our opinion. The relief is felt within seconds to minutes and, in our opinion, is best if followed by manual myofascial release of the spasms.

Diagnosis of trigger points depends on the accurate palpation with 2-4 kg/cm2 of pressure for 10 to 20 seconds over the suspected trigger point to allow the referred pain pattern to develop [97].

A study [98] of 17 patients with whiplash injuries suggest that myofascial trigger points served to "perpetuate lowered pain thresholds in uninjured tissues" [98]. It also added that the "lowered pain thresholds associated with central sensitization can be immediately reversed, even when associated with long standing chronic neck pain" [98]. This study also described an immediate increase in cervical spine ROM with average increase of 49% in flexion, 44% in extension, 47% and 28% in right and left lateral flexion respectively, and a 27% and 45% in right and left rotation, respectively [98].

A well-organized controlled, double-blind, cross-over study [99] sought to study the role of TPI in central sensitization related to whiplash injuries. It is known that central sensitization with low peripheral pain thresholds is a common finding among patients with chronic pain after whiplash [99]. It has been suggested that myofascial trigger points may act as modulators of central sensitization [99]. The study recruited 31 patients with chronic pain (trapezius myalgia) and centra sensitization after whiplash and did sham comparison. It concluded that peripheral pain threshold was likely modulated by myofascial tender points in selected patients with central sensitization [99].

Another study [100] looked at the usefulness of sterile water or normal saline in trigger point injections in 40 patients with whiplash syndrome. A maximum of three treatments were given during the first two months of the study and the patients were followed up for 8 months [100]. Neck pain and cervical spine mobility were monitored. After 3 months, the mean total mobility of the cervical spine increased by 39 degrees in the sterile water group versus 6 degrees in the saline group [100]. Three months later, 19 of 20 patients in the sterile water group assessed their condition as "generally improved" but only 6 in the saline group felt they improved [100].

The authors will not be able to enumerate all the other interventional options in this manuscript due to limits on reference numbers but will elaborate in further articles.

Conclusion

From the published data that we reviewed herein, it seemed very clear this debilitating injury is more than a 'whiplash'; it is a syndrome that is a dis-ease and has its own entity. We covered etiologies, biomechanics, diagnosis, management, and prognosis. We have read over 250 published manuscripts, and it seemed evident that the present status of whiplash is in disarray. The present guidelines and census of diagnosis and treatment is mediocre to say the least. This needs to change to prevent the long term sequalae of disability and the curse of central sensitization. As it stands now, the long-term prognosis of patients with whiplash injury-related neck pain is poor to say the least. It is our hope more research and organized guidelines and management options will elevate the present outcome of whiplash injuries.

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