Review

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Unveiling the Vital Role of Critical Neck Protection Devices for Motorcycle Riders: A Review

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Abstract: Fatal motorcycle accidents on- and off-road continue to be overlooked in the literature. Research is scant on morbidity and mortality due to neck injury, which leaves patients and their families debilitated chronically. Great Lakes EMS Inc. conducted a 10-year retrospective case study, which highlighted that motocross riders who do not wear a neck brace are at an 89% higher risk of a critical cervical spine injury; highly unstable cervical spinal fractures have a sustainably higher risk of morbidity and mortality. Proposed mechanisms of motocross neck braces displace the forces on the neck onto the helmet of the rider to provide a smooth distribution of forces, whereas lack of neck brace use places riders at risk for upper cervical spine fractures such as Jefferson fractures, Hangman's fractures, and Odontoid fractures. Further, evidence suggests the use of back protectors may increase the risk of thoracic and upper spine injuries during a motorcycle crash. The limited data on this topic continues to be a challenge, as there is a lack of understanding of the nature of these injuries, which are likely preventable with proper neck protection.

Keywords: SCI; TBI; neck Injury; motocross; motorcycles; neck brace

1. Introduction

Motorcycle crashes in the US continue to be a prevalent burden to the medical community and to those who are involved. In 14% of all fatal traffic collisions, a motorcycle is involved, [1] and the continued incidence of severe injuries in riders has been made clear in clinical data reports. According to a study by Medina et al. 2020 [2] that employed registered vehicle data, despite making up just 2.8% of all vehicles, motorcycles were responsible for 20% of spinal cord injuries (SCIs) that were reported. [2] Both off-road racers and street motorcycle riders inherently have a serious risk while not wearing a neck protection device. *Great Lakes EMS Inc.* [3] founded in Northern Wisconsin, oversees national motocross events and typically encounters over 1000 riders in a single given weekend. In their non-peer-reviewed case study, a critical cervical spine injury in motocross riders is 89% times more likely without a neck brace shown with over 9430 total patients whom 8529 fell into the criteria of "wearing (or not wearing) a neck brace." [3]

A five-year retrospective analysis that was conducted at a level 1 trauma hospital in Wisconsin between January 1, 2010, and January 1, 2015, concluded that the number of vertebral fractures and ligamentous injuries of the cervical spine sustained by motocross riders who were not wearing a helmet or neck brace was statistically greater compared to the number of injuries sustained by riders who were. [4] Additionally, clinical data from the National Trauma Data Bank (NTDB) (2007–14) showed that the causes of injury and outcomes and mechanisms were different between street and motocross accidents. Per findings reported in the paper, street motorcycle riders had a higher incidence of morbidity and mortality as opposed to motocross racers, and both rider demographics consisted highly of adolescent males. Further, motocross riders are more likely to wear protective off-roading gear, and they tend to show a much lower correlation with alcohol use while riding.[4]

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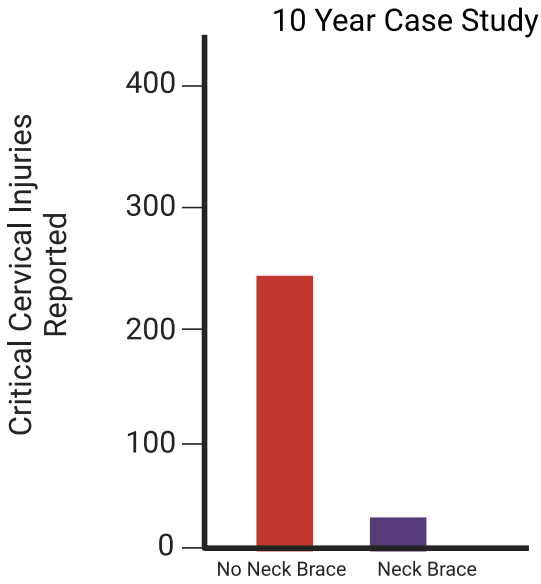

Figure 1. Highlight from a non-peer-reviewed case study presented by Great Lakes EMS Inc[3] showing the differences in those who wear a neck brace vs those who do not and suffer a critical cervical spine injury. (Created with BioRender.com).

Neck protection devices have been limited in the preclinical data and studies with supporting evidence that there is a significant benefit to riders wearing neck protection. Riding a motorcycle comes with an inherent risk to riders because an uncovered neck may provide a landscape of susceptibility in the event of a motor vehicle collision. Detailed autopsies of 73 motorcycle accident fatalities showed high frequencies of neck injuries in both the helmeted and non-helmeted riders. Another finding of this report was the significant presence of injury to soft tissues and neurovasculature of the neck without any obvious external evidence of such injuries.[5]

Nevertheless, it is difficult not to recognize that motorcycle helmets, while essential for head protection, may not adequately protect the specific vulnerabilities of the neck. To produce the best protection for the neck, it is important to know the characteristics of devices that successfully protect the head and neck.

2. Pathophysiology

The cervical spine is composed of vertebrae C1 to C7 and is further divided into two regions, the craniocervical junction (C1, C2, and Occiput) and the sub-axial spine (C3-C7).[6] The cervical spine bears the weight of the cranium and head and grants movement to the region. The cervical spine has great mobility as compared to the thoracic spine, allowing for flexion, extension, rotation, and lateral flexion.[6,7] This increased mobility increases the risk of injury to this spinal cord segment with the most common areas of injury being the C2, C5, C6, and C7 regions.[7,8] There multiple mechanisms of injury related to the direction of impact and position of the head and neck at impact: compressive flexion, vertical compression, distractive flexion, compressive extension, and lateral flexion.[7,8] Furthermore, the injuries can be classified as whiplash (soft-tissue injuries), neck fractures, and cervical spinal cord injuries. [7,9]

Whiplash injuries often happen during low-velocity rear-end collisions as the cervical spine experiences sudden hyperextension followed by hyperflexion, or hyper-lateral flexion.[7,10] This mechanism of action can lead to neck instabilities within the craniocervical junction region, including atlantoaxial instability and occipitocervical dislocations. Atlantoaxial instability includes rotatory

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instability, C1-C2 horizontal displacement and distraction injuries, and atlanto-dens instability. [10] Occipitocervical instabilities are caused by due disruption of ligaments between the occiput and C1 vertebrae.[7,10] Whiplash injuries are classified on a whiplash-associated disorder (WAD) 1-5 scale based on the severity of all WAD 1 injuries including those of the often-injured anterior longitudinal ligament and WAD 2 including dislocated or unilateral locked facets. [10]

Riders are at greater risk of suffering one of these injuries in accidents involving a topside/highside collision or a head-leading collision. A topside collision occurs when the rider flips over the handlebars, while a highside collision occurs when the rider is thrown opposite the turn direction due to improper correction. Head-first collisions occur when the rider's longitudinal body axis is aligned parallel with the collision velocity, often occurring post-ejection. [10] The common neck fractures include Jefferson fractures, Hangman's fractures, and Odontoid fractures.[7,10,11] Jefferson fractures are vertebral compression fractures of the Atlas (C1) that occur during axial loading upon impact, often resulting in shifting of the lateral masses and subsequent fractures of the posterior and anterior arch and disruption of the transverse ligament.[9-11] Hangman's fractures are fractures of the Axis (C2) that happen during hyperextension and compression of the spine resulting in a displacement of C1 and C2.[7,9] Odontoid fractures occur under flexion and affect the odontoid process, or dens, of C2 that C1 pivots on. These fractures are common in low-impact injuries in the elderly and high-impact injuries in young adults. These fractions are unstable and further categorized into 3 types: type I fractures occur on the odontoid process above the transverse ligament, type II fractures occur at the base, and type III fractions extend laterally into C1.[7] Cervical spinal cord injuries are detrimental to health and occur most often due to flexion, followed by compression, and hyperextension.[9] Compression mechanisms of injury cause a high level of displacement on the anterior spinal cord displacement, while flexion and extension mechanisms cause a posterior displacement and stress of the spinal cord. [9,10]

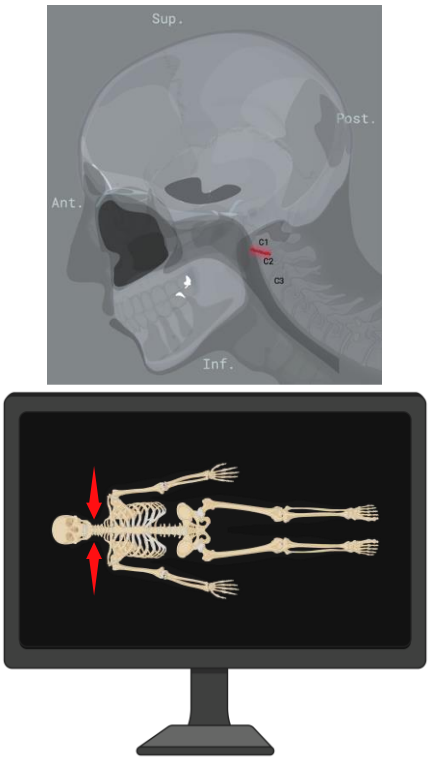

Figure 2. Animation representation of an odontoid fracture of C2 dens. (Created with BioRender.com.) (*Adapted from "Intracranial Electrodes", by BioRender.com (2023). Retrieved from https://app.biorender.com/biorender-templates*).

While motorcycle helmets reduce the risk of mortality and head injury in motorcycle riders who crash, it is not well understood how helmets affect neck injuries.[12,13] Some researchers have argued

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that motorcycle helmet use decreases rider vision and increases neck injuries due to increased weight and torque applied to the head.[14] While such arguments might seem plausible, it is important to note that helmet use and proper fixation provide effective protection to motorcyclists' heads. From the three major mechanisms of injury (blunt trauma, penetrating trauma, and strangulation), motor vehicle accidents are considered blunt trauma.[15] Such injuries might present as "delayed presentation of laryngeal, vascular, digestive tract injuries" or surface any occult cervical spine injuries. Direct damage or excessive rotation and/or hyperextension causes stretching of the arteries and veins resulting in a shear injury of vessels. Due to ethical concerns, limited research has been conducted on motorcycle-related trauma to the neck. However, if we assume that traumatic motorcycle incidences closely resemble sport-related head and neck injuries due to high-impact and unpredictable routes of force transfer, then some connections could be made between neck strength and reduced neck-related injury. When it comes to pre-therapy in preventing neck injury, neck strengthening exercises could be employed to increase neck stability and reduce the risk of injury during motorcycle accidents. A study of rugby players concluded that a stronger neck may assist in reducing head and neck injuries including concussions.[16] Other supporting studies have concluded that "incorporating neck exercises into injury reduction exercise programs [reduces] the incidence of sport-related head and neck injuries. The same neck-strengthening exercises that rugby players use to "assist in reducing head and neck injuries including concussion" could be used for motorcyclists.[17]

One important consideration is that the neck flexor muscles may require an increased amount of training because they are generally weaker than the extensors[17] and play a more pivotal role in reducing whiplash forces. Consequently, exercises that focus on the force-producing capacity of the neck flexors and reducing strength imbalances between the flexors and extensors will be imperative in reducing trauma-related neck injuries.[16]

3. Protective Gear

To no surprise, full-face helmets would result educed head and neck injuries in motorcycle accidents when compared with partial and open helmets.[18] One study found a -0.64 mean difference between injury severity of head and neck for helmeted and non-helmeted motorcycle accidents.[19] Studies show that severe hyperextension and hyperflexion are the primary mechanisms of harm for neck injuries in motorcycle accidents.[20] Preventing such movements would be of benefit for motorcycle riders in such situations.

When comparing full-face bike and motorcycle helmets to open-face and a modified full-face airbag helmet, it was found that full-face motorcycle helmets reduced mid-face injuries while slightly increasing lower-face injuries. Open-face helmets offered no significant protection against facial or brain injury, while both full-face helmets and the modified airbag helmet reduced brain injury. Although both full-face helmets and the modified airbag helmet were effective in preventing head injury, they may increase strain on the neck and basilar skull, increasing the risk for neck injury.[21] Additionally, the protective characteristics of a given motorcycle helmet, based on national standards, often test a helmet's protective capability to linear impact but neglect to test effectiveness against oblique or angular impact. These findings also contribute to the pathology seen in a diffuse axonal injury TBI. [22] Thus, some propose further testing is required to better prevent neck injury in all scenarios.[23]

A few papers have demonstrated the potential effectiveness of neck protection devices in minimizing the severity of neck injuries in motorcycle accidents. One experimental study found an updated SUFEHN-Model of neck brace was able to extract forces at collision from each cervical vertebral level as well as the occipital condyle for velocities lower than 5.5 m/s (12.3 mph), but the neck brace was insufficient for impact velocities above 6.5 m/s (14.5 mph).[24] A more recent study showed promise for a new head and neck safety device (NHNS) for motorcycle racing. The device is composed of a helmet linked to the rider's jacket with several cables and stop surfaces to limit the flexion and extension of the neck. Experimental tests of the safety device were run using a Hybrid III dummy, which showed the NHNS has the potential to reduce neck damage in some crash situations. The effectiveness of the device stemmed from reducing the load on the rider's neck and maintaining

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the vertebrae rotations "within physiological limits".[25,26] Per off-road company *Alpinestar*, their most popular neck brace, the BNS Tech-2, provides "[f]unctions when the rider's helmet makes contact with the frame at the moment of a crash, thus providing a clean, solid surface which instantly channels damaging, compressive impact energy away from the neck and on to the BNS"; this helmet is under Category 2 PPE - CE Certified Under EU Regulation 2016/425. [27] The price point for this neck brace is roughly 329.95 USD.

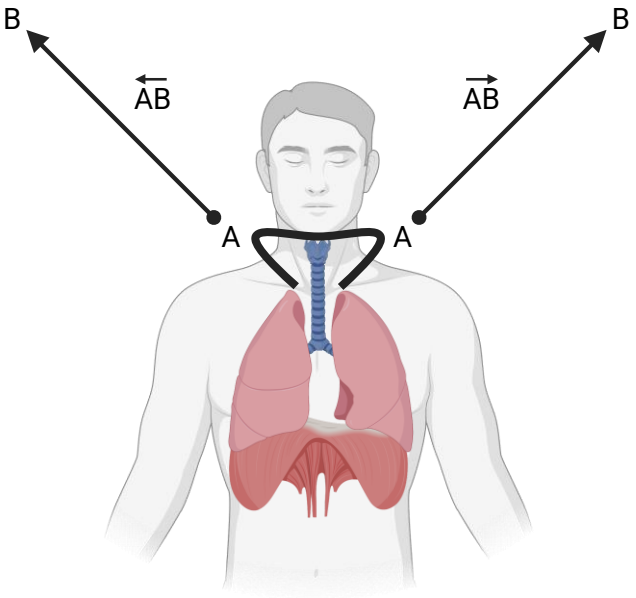

Figure 3. The image above depicts BNS Tech-2[27] and the proposed mechanism of action[28] via the distribution of vector forces away from the head and neck area. (Created with BioRender.com.).

Other devices that have been tested include a SCI and brain injury test structure (SCIBITS) consisting of a continuous head and neck shield connected to a thoracic jacket made of fiberglass. When compared to a traditional motorcycle helmet or no helmet, both of which surpassed the threshold for brain injury and SCI, the SCIBITS may show to be protective against SCI and partially protective against brain injury.[26] Additionally, a systematic literature review looked at different types of protective jackets that are currently being used. Jackets with foam inserts were compared to their hard-shell counterparts. Foam inserts showed little to no effectiveness while hard-shell jackets showed the potential to prevent SCI. However, there is not enough data for a clear conclusion on this method of protection.[29] Another study looked at 124 patients who suffered back injuries from motorcycle accidents. When comparing those wearing a back protector at the time of the accident to those who did not, back protectors showed little to no significance in preventing thoracolumbar injuries to the spine – it was proposed that back protectors may even deflect injury from the lumbar region to the thoracic region.[30]

Table 1. Patient comparison of those with and without back protectors at the time of injury vs with and without spinal injuries.[30].

124 Total Patients	Number of patients with a back injury	Number of Thoracolumbar Injuries
Number of patients with Back Protector (**53**)	29	57

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Number of patients without Back Protector (**71**)	28	75

4. Discussion

In the presented review, the sparse represented data on the use of wearing a protective neck device while operating a motorcycle on or off-road does highlight the reduction in a potentially fatal event. Interestingly, there is support that the use of back protectors may result in a poor outcome due to the increased risk of injury to thoracic regions of the spine.[30,31] Moving forward, it is critical to push for developing a cost-effective and researched-backed option for neck protection in motorcycle riders globally. Adolescent males pose the greatest risk for cervical spine trauma[4] and mortality on motorcycles where there is a continued lack of education on the importance of wearing proper neck protection equipment. There also may be significant benefits from neck strengthening protocol for motocross athletes and motorcycle riders to reduce the rate of morbidity and mortality following a crash.[17] A collective effort must be made to highlight the importance of proper equipment for motorcycle riders of all types and ages.

5. Conclusions

Neck braces provide improved protection for those who ride off-road motocross, and there is a need to improve the technology of commercial neck braces for those who ride motorcycles on the street. Wearing a full-face helmet for on-road street riders reduces the risk of morbidity and mortality, but there is still limited data on the use of neck braces for on-road street riders.

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