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ORIGINAL ARTICLE

Mechanisms of Cervical Spine Injuries for Non-Fatal Motorcycle Road Crash

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Summary

Cervical spine injuries such as subluxation and fracture dislocation have long been known to result in severe consequences, as well as the trauma management itself. The injury to the region has been identified as one of the major causes of death in Malaysian motorcyclists involved in road crashes, besides head and chest injuries (Pang, 1999). Despite this, cervical spine injury in motorcyclists is not a well-studied injury, unlike the whiplash injury in motorcar accidents. The present study is a retrospective study on the mechanisms of injury in cervical spine sustained by Malaysian motorcyclists, who were involved in road crash using an established mechanistic classification system. This will serve as an initial step to look at the cervical injuries pattern. The information obtained gives engineer ideas to facilitate design and safety features to reduce injuries.

All cervical spine injured motorcyclists admitted to Hospital Kuala Lumpur between January 1, 2000 and December 31, 2001 were included in the present study. Based on the medical notes and radiological investigations (X-rays, CT and MRI scans), the mechanisms of injuries were formulated using the injury mechanics classification. The result shows that flexion of the cervical vertebrae is the most common vertebral kinematics in causing injury to motorcyclists. This indicates that the cervical vertebrae sustained a high-energy loading at flexion movement in road crash, and exceeded its tolerance level. The high frequency of injury at the C5 vertebra, C6 vertebra and C5-C6 intervertebral space are recorded. Classification based on the Abbreviated Injury Scale (AIS) is made to give a view on injury severity, 9.1% of the study samples have been classified as AIS code 1, 51.5% with AIS 2 and 21.2% with AIS 3.

Key Words: Cervical injury, Injury mechanisms, Motorcycle road crash

Introduction

The neck injury has long been known to pose a death threat to motorcyclists in road crash. Besides, the neck carries several vital structures such as phrenic nerve and part of the origin of brachial plexus. Injuries to these will cause numerous complications. The study on motorcycle road crash has indicated that the neck injury as one of the major single causes of death in Malaysian motorcyclists (Pang, 1999).

The road crash casualties reported using data available in Micro-computer Accident Analysis Package (MAAP 5) at the Road Safety Research Center (RSRC), University Putra Malaysia, indicates that 525 fatal and hospitalized neck injury cases involving motor vehicle

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road crash occurred from year 1998 to midyear 2000 (fatal cases contribute about 18.3%). This information is representable to national statistics as the database at RSRC is constantly synchronized with the national accident database at Royal Malaysian Police (PDRM). Motorcyclists contributed about 50% of the figures. As such, a proper investigation on the injury is needed.

Although several experimental studies have been conducted on neck injury subjects in vehicle crash (Anders et al, 2000; Svensson et al, 2000), especially the well-known whiplash injury, the phenomenon in motorcyclist road crashes has not yet been established. Part of the reason may be due to different road environments in developed countries, which has low frequency of use of motorcycle. In Malaysia, the motorcycle continues to be a popular mode of tran[illegible]t for many decades.

Bogduk and Mercer (2000) stated that neck injury mechanisms should be studied from the cervical vertebrae, as it pre-determine the possible neck movements. Hence, initial study on the cervical injury sustained by motorcyclists is required, based on a sound understanding of the mechanisms of cervical injury sustained by motorcyclists. Real world road crash information is needed, besides the results from laboratory tests using dummies.

Biomechanics of Cervical Vertebrae

The cervical vertebrae, identified as C1- C7, are perhaps some of the most unique and interesting parts of the spine. They are the most mobile region of the vertebral column and are crucial in supporting the weight of the head and the neck itself throughout life. A fundamental kno[illegible]dge in anatomy is important to understand the bion[illegible]chanics of the cervical spine, before any study of injury mechanisms.

The cervical lordosis is the least distinct curve of the spinal structure, but it behaves like all the spinal curves and helps to absorb the load applied to the spine. The cervical spine is generally described in three parts, the atlanto-occipital, atlanto-axial, and the lower cervical joints (C2- C7).

The atlanto-occipital joint forms the link between the head and the atlas. The possible movements at this joint are flexion and extension motions. The movements are achieved by the condyles rolling and glide across the socket. This allows the head to flex or extend and indicate "yes". Under normal conditions, flexion is limited by the tension in the posterior neck muscles and impaction of the submandibular tissues against the throat, while extension is limited by the occiput compressing the suboccipital muscles.

The axis carries the head and the atlas through atlanto-axial joints. Besides weight bearing, the cardinal function of the atlanto-axial junction is to permit a large range of axial rotation. The movements are achieved by the pivoting of the atlas on the odontoid process and sliding on its ipsilateral aspect.

The motions for the cervical region from C2-C3 through C7-T1 are flexion, extension, lateral flexion and axial rotation. Usually the range of extension of the lower cervical spine is greater than flexion. Extension, being limited below by the inferior articular processes of C7, enters a groove below the superior articular processes of 1st thoracic vertebra (T1). The flexion motion, on the other hand is limited by the lips of the anterior and inferior aspect of the cervical vertebral bodies pressing against anterior and superior aspect of the vertebral bodies below. Lateral flexion of the cervical spine is accompanied by the rotation of the vertebral bodies into the concavity formed by the lateral flexion.

The tremendous clinical concerns regarding injury to the cervical region has prompted researches into various biomechanical analyses to understand the mechanical and kinematic properties of the cervical spine.

Materials and Methods

In the present study, motorcyclists sustaining injury and admitted to the orthopedics ward, General Hospital Kuala Lumpur, Malaysia, between January 1, 2000 and December 31, 2001 were selected for the study. The details of the motorcyclist were obtained from the admission records. Opinion from the physician or surgeon treating the motorcyclist was also obtained. Age of the motorcyclist and the history of injury and other diseases of the patient were crucial. Any diseases or other factors, which may contribute to the cervical injury, such as rheumatoid arthritis, were noted.

The diagnosis of injury and descriptions were obtained from the patient's case notes. The injury sustained by motorcyclists were then coded and categorized into severity differences using the Abbreviated Injury Scale

(AIS), 1990 revision (update 98). The AIS scales from 1 for the minor injuries and up to 6 for critical (Table I).

The X-ray, CT-scans and MRI (magnetic resonance imaging) with the radiologist reports were then used to identify the types of injury, such as wedge fracture and uncinate process fracture. Roaf (1964), analyzing cervical radiograph, has shown that injuries to the vertebrae can be studied retrospectively, to identify injury mechanisms. By using pictures and diagrams drawn about the injury types, the causes and mechanisms of injury can be translated into mechanical categories. However, the odontoid fracture has been reported to have imprecise mechanism of injury. Based on finite element model study (Putthz et al, 2000; Graham et al, 2000), lateral shear force and extension kinematics were observed to cause the fracture. The information is added into injury mechanisms classification table (Table II). The classification in the table was then used to group the injury mechanisms of cervical spine to study the kinematics of neck motion during road crash.

Results and Discussion

During period of study, there were 70 patients identified as having sustained cervical injury and admitted to the orthopedic wards, Hospital Kuala Lumpur, under Motor Vehicle Road Crash (MVA) category. They consist a wide range of road users like drivers, bicyclists, pedestrians and others. Apart from that, 17.1% of the medical records have successfully been traced and identified as motorcyclists, who sustained injuries from road crash. As the data collected from the 33 medical reports, 97% of them had record of neither neck injury history nor diseases that associated with bone deformities. All the selected cases were male motorcyclists, and 72.7% of the victims aged between 16 and 29.

In injury investigation, the AIS has been widely used, cervical injuries arising from the road crashes have been categorized according to AIS score (severity differences). In this study, it is suggested that cervical spine injury with AIS 2 and 3 should be categorized as major injury, and with AIS 4 and 5 is categorized as severe injury as it causes severe life threatening neurological problems.

As seen in Table III, about 50% of the cases obtained from Hospital Kuala Lumpur came under category AIS 2. These cases usually observed with fracture vertebrae (Figure 2) and need supervision from medical staff with careful trauma management. The number of AIS 1 patients, which shown 9.1% in this study may have larger number of them in population. Since minor injury (AIS 1) such as soft tissue injury is treated as out patient and large number of the cases were probably omitted due to incomplete hospital records.

Fracture of the odontoid and vertebral facet usually code with AIS 3 because it poses an unstable fracture to the vertebral column and structure, and leads to further injury to the spinal structure. Any injury that provides neurological complications, such as quadriplegia and tetraplegia is coded AIS 4 or 5 and considered as severe case. In the present study, cases with AIS 4 and 5 were observed to have subluxation and dislocation type of injuries. These type of injuries were not stable, and at high risk of impinging on the spinal cord or spinal nerves (Figure 3). Most of the patients have life long disabilities. The present study rules out fatal cases, which is classified as AIS 6.

When the collected data were analyzed by injury frequency according to injury location, an anatomical pattern was observed as shown in Table IV. Injuries of the cervical spine did not occur at one part, but involved numerous vertebrae, such as vertebrae C4, intervertebral disc C4-C5 and vertebrae C5.

Table IV shows that most of the injury occurred at the lower parts of the cervical spine, the C5, C6 and the intervertebral joint between C5-C6 were the most frequently injured location sustained by motorcyclists, constituting about 43% of all the site of injury. The finding shows good correlation to the study of human head-neck computer model upon impact (Kabo 1983), the cervical spine was reported to experiences it maximum mobility in the region of C5 to C6 under loading. Present study recorded high frequency of cervical spine injury at lower cervical spine, especially at vertebrae C5, intervertebral C5-C6 and vertebrae C6. However, the movement of the neck should be taken into consideration when investigating the injury, so that the injury mechanism can be ascertained.

Investigations using X-rays and CT- scans have provided evidences of injury sustained by the motorcyclists and made the identification of injury type possible. According to John (1996), mechanical causes for certain type of injury can be identified based on radiographic images.

The flexion and axial compression motions were the most frequent cervical spine injury mechanisms, sustained by motorcyclists in road crashes. Figure 4 shows a typical injured cervical spine due to such motions. It should be noted that most of the injury do not exist with a single cervical kinematics; a combination of two or more may create the injuries, such as flexion-compression. Figure 2 is an example of teardrop vertebral fracture, which produced an anterior-inferior corner fracture fragment and a sagittal fracture through the vertebral body. This type of fracture has been known to be cause by a flexion-compression mechanism. However, present study only counted the pre-dominant cervical kinematic (Table V).

Even within the normal physiological movement, more than one kinematic element can occur within the vertebrae column in a single movement. The coupled motion has been known to share these characteristics in lateral flexion. This has made the classification tasks more difficult if the investigation is based only on the injured cervical bones itself. The existence of other injuries like head injury and body laceration has been incorporated to predict the neck motion during road crash. The rational behind is due to the fact that the neck motion is related to the motions of head and the body (Portnoy, 1971).

It is postulated that the motorcyclist's neck may flex in a road crash. This causes the normal cervical lordosis to disappear and the cervical vertebrae are aligned axially. In this position, the cervical spine becomes a segmented column that lacks the concave structure, which is required for energy-absorption in neck bending. The neck structures, especially the cervical vertebrae will have to absorb all the loading energy. When the energy exceeds the capacity of the cervical structures, failure will occur. Disruption of this structure had been known to cause further flexion or rotation of spine (Whitting, 1998) and associated with subluxation or dislocation injury observed in Figure 4.

Table I: The neck injury AIS coded for motorcycle rider in road crash

AIS	Description
1	Minor - e.g: Strained spine, acute with no fracture or dislocation.
2	Moderate - e.g: Disc injury without nerve root damage.
3	Serious - e.g: Cord contusion with fracture.
4	Severe - e.g: Incomplete cord syndrome with fracture.
5	Critical - e.g: Complete cord syndrome C4 or below.
6	Maximum - e.g: Complete cord syndrome C3 or above.
9	Unknown

Table II: The classification of injuries according to the mechanics cause

Mechanistic Classification for Cervical Spine Injuries	
Injury types	**Cervical motion**
Hyperflexion sprain Bilateral interfacetal dislocation Simple wedge (compression) fracture Flexion teardrop fracture	Flexion
Unilateral interfacetal dislocation	Flexion-rotation
Odontoid fracture	Extension-lateral shear/compression
Burst (bursting, dispersion, axial loading) fracture Hyperextension dislocation Avulsion fracture of anterior arch of atlas Extension teardrop fracture of the axis Fracture of posterior arch of atlas Laminar fracture Hyperextension fracture-dislocation	Vertical compression Hyperextension
Uncinate process fracture	Lateral flexion

Table III: The frequency of Abbreviated Injury Scale (AIS) sustained by motorcyclists in cervical injury

AIS score	Frequency	Percentage
1	3	9.1%
2	17	51.5%
3	7	21.2%
4	1	3.0%
5	5	15.2%
Total	33	100.0%

Table IV: Injury frequency according to the injury location sustained by motorcyclist

Injury location	Frequency (fracture)	Injury location	Frequency (subluxation)
C1	1	C1-C2	1
C2	3	C2-C3	3
C3	2	C3-C4	2
C4	8	C4-C5	2
C5	11	C5-C6	6
C6	11	C6-C7	4
C7	8	C7-T1	3
Total	44	Total	21

Table V: The proportion of cervical mechanics into it's causing injury

Cervical motion	Frequency of injury	Proportion
Lateral Flexion	4	0.121
Flexion	14	0.424
Axial Loading/ compression	8	0.242
Extension/ hyperextension	4	0.121
Horizontal impact/ others	3	0.091

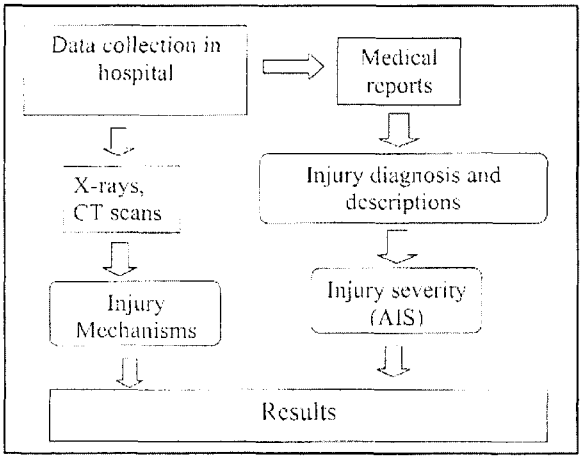

Fig. 1 : The flow-chart of the methodology

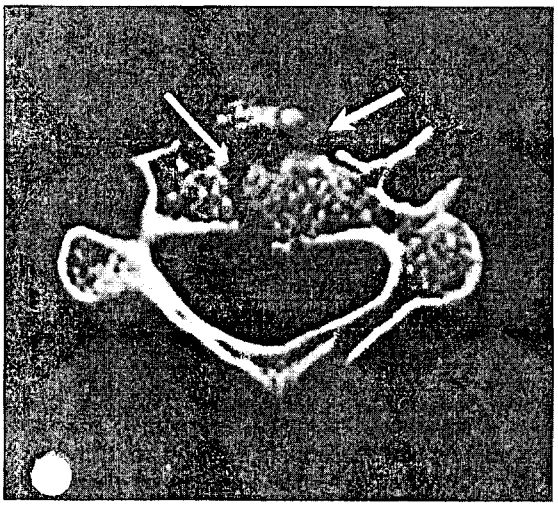

Fig. 2 : Axial cut (CT) though vertebrae body is cervical region, the arrows showing fractures of the body

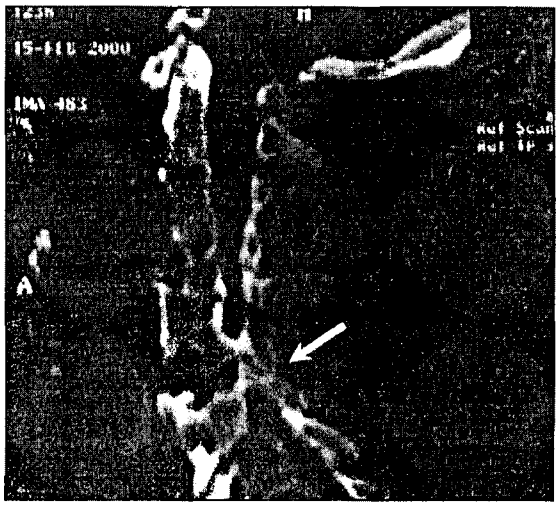

Fig. 3 : Sagittal cut (MRI) showing C5-C6 subluxation of cervical spine

Fig. 4 : A 3D CT image shown fracture dislocation to the cervical vertebral column, the patient sustained incomplete neurological dysfunction

Conclusion

The present study has shown a correlation with the computer simulation study on head-neck response to loading by Kabo (1983). The outcome shows that C5 and C6 are easily susceptible to injury in motorcycle road crash. Present study has identified that the flexion motion and compression mechanisms are the two most common injury mechanisms sustained by Malaysian motorcyclists in road crashes. As such, steps should be taken to reduce or absorb the loading energy when the neck flex. Padding materials with proper design may be added to reduce the severity of cervical spine injury in road crash.

This information may serve as a basis for further action. Based on the fundamental knowledge in human anatomy and mechanics, the angle of neck movement and tolerate energy loading should be studied. Analysis on soft tissue and bone stiffness through experimental and analytical studies may help to provide further information in designing a proper restrain system to minimize the neck injuries during road crash.

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