UNIVERSITI PUTRA MALAYSIA

RELATIONSHIP BETWEEN NECK MUSCLE ACTIVATION AND HEAD-NECK RESPONSE IN LOW VELOCITY FRONTAL COLLISION

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AND HEAD-NECK RESPONSE IN LOW VELOCITY FRONTAL COLLISION

BY

KAK D-WING

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January 2016

Chair: Wong Shaw Voon, PhD
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Neck injury is not a rare occasion in car crash accident. Occurrence of neck injuries due to car crash accident has increased 11 times within 20 years in Netherlands. Road Safety Research Center (RSRC) of UPM reported that 60% of all neck injuries resulted to fatality of motorcyclist in road collision at Malaysia. High expenses are spent on medical, insurance and hospitality on neck injury related to car crash annually. Proper countermeasure has to be taken to mitigate the occurrence of neck injury in crash. Previous study has proven that neck active muscle is capable to generate force to reduce 30-35% of head rotations and head angular velocities in rear-end collision. Thus, it is critical to understand the behavior of neck muscle responses before a biofidelity head-neck mathematical model can be designed. Nevertheless, the behavior of neck active muscle response under static and dynamic loading is still yet to be established. This study aims to establish relationship between neck muscle response and head-neck response in low speed collision through experimental test. In this study, there are two main experimental test which are static neck muscle strength test and low velocity frontal collision test. Neck muscle *sternocleidomastoid* and *semispinalis capitis* which are primary neck flexor and extensor are selected to be studied in this study. In static neck strength test, the measured maximum neck muscle strength is 64.5 N and 96.7 N for flexion and extension. This study has established models to relate neck muscle EMG activity and neck muscle force for neck flexor and extensor muscles. This model can explain 82.9%-85.4% of the data variables with a negative quadratic relationship. The neck muscle force generated at the same activation level is different between static and dynamic loading condition. In low velocity collision test, the peak linear head accelerations are 4.61G and 7.35G relative to torso for impact speed of 2.17 m/s and 2.47 m/s respectively. An empirical model has established to relate neck muscle activation level based on head linear acceleration and angular acceleration where R^2= 0.934. Neck extensor, *semispinalis capitis* are the dominant muscle with high level of activation level in low velocity frontal collision test. On the hand, neck flexor, *sternocleidomastoid* only activated at about 30-40% in the collision tests. The established empirical models can be applied to relate neck muscle activation level and muscle force in low velocity frontal collision. This can further enhance accuracy and precision of current head-neck simulation model in simulating kinematic response of human head in crash.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia Sebagai memenuhi keperluan untuk ijazah Master Sains

HUBUNGAN ANTARA PENGAKTIFAN OTOT LEHER DAN TINDAK BALAS KEPALA-LEHER DALAM PELANGGARAN DEPAN PADA HALAJU RENDAH

Oleh

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Kecederaan leher bukan perkara yang jarang dalam kemalangan jalan raya. Kecederaan leher disebabkan kemalangan jalan raya meningkat sebanyak 11 kali ganda dalam tempoh masa 20 tahun di Netherlands. Pusat Penyelidikan Keselamatan Jalan Raya UPM juga melaporkan bahawa 60% daripada kecederaan leher melibabtkan kematian bagi penunggang motosikal yang terlibat dalam kemalangan jalan raya di Malaysia. Pembelanjaan tinggi diperlukan bagi perubatan, insurans dan servis hospital untuk masalah tersebut. Maka, langkah penambahbaik diperlukan untuk mengurangkan masalah tersebut. Kajian sebelum ini telah membuktikan bahawa otot leher berupaya untuk menghasilkan daya bagi mengurangkan putaran kepala sebanyak 30-35% dalam pelanggaran dari belakang. Usaha dalam memahami tinkah laku otot leher adalah kritikal sebelum matematik model kepala-leher yang *biofidelity* dapat diwujudkan. Namun begitu, model yang boleh menjelaskan aktiviti otot leher pada keadaan statik dan dinamik masih belum dibina. Kajian ini bertujuan untuk mewujudkan satu model untuk menjelaskan hubungan antara tindak balas otot leher dan tindak balas pergerakan kepala-leher bagi kemalangan kelajuan rendah melalui eksperimen. Terdapat dua eksperimen utama dalam kajian ini, iaitu ujian kekuatan otot leher dan ujian perlanggaran depan kelajuan rendah. Otot leher *sternocleidomastoid* dan *semispinalis capitis* sebagai *flexor* dan *extensor* utama telah dipilih untuk dikaji. Melalui ujian tersebut, kekuatan otot leher adalah 64.5 N dan 96.7 N untuk *flexion* dan *extension*. Kajian ini telah menghasilkan model berkaitan hubungan antara aktiviti EMG dan kekuatan otot leher. Model ini dapat menjelaskan lebih daripada 80% pembolehubah. Kekuatan otot leher adalah berbeza antara keadaan statik dan dinamik. Dalam ujian pelanggaran halaju rendah, pecutan linear kepala relatif dengan badan adalah 4.61G dan 7.35G bagi kelajuan impak 2.17 m/s dan 2.47 m/s. Satu model telah dihasilkan untuk menganggarkan tahap pengaktifan otot leher berdasarkan pecutan linear dan putaran kepala. Sebagai *extensor* leher, *semispinalis capitis* diaktifkan dengan tahap yang tinggi dalam perlanggaran hadapan pada kelajuan rendah. Sebaliknya, otot *flexor, sternocleidomastoid* hanya diaktifkan pada tahap 30-40% sahaja. Semua empirikal model ini dapat digunakan untuk menganggarkan tahap pengaktifan otot dan daya yang dihasilkan pada perlanggaran kelajuan rendah. Ini adalah penting untuk meningkatkan ketepatan model simulasi kepala-leher.

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I certify that a Thesis Examination Committee has met on 27 January 2016 to conduct the final examination of Kak D-Wing on his thesis entitled " Relationship Between Neck Muscle Activation and Head-Neck Response in Low Velocity Frontal Collision" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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CHAPTER 1

INTRODUCTION

1.1 Background

The injury thresholds of human neck structure under different impact directions and loading conditions are determined for the purpose to predict neck injury in various situation of car crash accident. The neck injury criterions such as NIC (neck injury criterion), N_{ij} (Normalized neck injury criterion for frontal impact), and IV-NIC (Intervertebral neck injury criterion) were developed according to head and neck kinematic and dynamic motion during impact. The maximum permissible kinematic parameters such as head acceleration, axial force, shear force, moments and displacement are thoroughly being studied and tested to predict neck injury risks accurately. In order to do so, crash test using human subject is essential to obtain the kinematic parameters in verifying human head neck biomechanical responses. Nevertheless, this method is only limited to allowable physiological range of motion of human head-neck segment to prevent any unwanted injury to the human subjects. Beyond this point, crash test human dummy and post mortem human subject (PMHS) is used to predict human head-neck biomechanical response at more extreme collision condition. Nonetheless, the effect of neck muscle activation on human head neck response cannot be assessed and studied when crash test was conducted using human dummy or PMHS.

The study of neck muscle strength is essential to understand the biomechanics and dynamics of head-neck segment in crash. In low-speed motor vehicle collision, neck muscle is capable to produce forces in resisting against impact force which results in reduction of head/neck kinematic motion in frontal, lateral and rear impact (Horst, 2002). The responsible neck muscle groups have activated within 13.2 ms after the initial rotation of head (Magnusson et al., 1999). Furthermore, neck muscle activation level found to be increased with the increasing impact acceleration in frontal and rear-end collision (Kumar, Narayan, & Amell, 2002, 2003a). Thus, neck active muscle can provide certain level of protection to head-neck segment in injury reduction and prevention.

Neck active muscle is crucial to generate forces for head-neck motion and to maintain head-neck posture. The active component of skeletal muscle is responsible to generate such forces. The magnitude of force is dependent on muscle length, muscle contraction velocity, joint angle and muscle activation level. Furthermore, the intensity of neck muscle force is associated with the numbers of motor units action potential (MUAPs) being recruited and the firing rate of MUAPs. Electromyography (EMG) is a method to measure and evaluate the electrical activity in skeletal muscle as the result of recruitment of MUAPs. The frequency and amplitude of the electric current is the main indicator to determine the activation level and pattern of neck active muscle.

Maximum isometric neck muscle strength of a human being can be measured through exerting maximal effort on external loading applied to the head while sitting at upright neutral posture. It has been reported that neck muscle strength of male is significantly greater than female in both flexion and extension direction which indicated that physical properties of neck structure are difference between genders (Chiu, Lam, & Hedley, 2002; Jordan, Mehlsen, Bülow, Østergaard, & Danneskiold-Samsøe, 1999; Kumar, Narayan, & Amell, 2001a; Suryanarayana & Kumar, 2005; Valkeinen, Ylinen, Mälkiä, Alen, & Häkkinen, 2002; Vasavada, Li, & Delp, 2001).

1.2 Problem statement

Neck injury is not a rare occasion in car crash accident. Half of the car to car accident may result to neck injuries according to a study in Japan (Ono, Kaneoka, Wittek, & Kajzer, 1997). In addition, occurrence of neck injuries due to car crash accident has increased 11 times within 20 years in Netherlands (Stovner, 1996). Road Safety Research Center (RSRC) of UPM reported that 60% of all neck injuries resulted to fatality of motorcyclist in road collision at Malaysia (Yen et al., 1999). As a prevalence issue, high expenses are spent on medical, insurance and hospitality on neck injury related to car crash annually. Whiplash injury or soft tissue cervical injury is being reported frequently in car accident which is due to inertial effect by relative motion between head and thorax. In Europe, low velocity car crash, ranging from 10 to 15 km/h, leads to 65% of whiplash injury which requires insurance companies to pay $10-20 billion every year (Castro et al., 1996). As high as $2.7 billion has been spent for AIS 1 (Abbreviated Injury Scale) yearly in USA (Kleinberger, 1993). In Sweden, the Swedish Society of Medicine announced that the total cost of whiplash injury is approximately 500 million euros (Commission, 2011). Thus, proper countermeasure has to be taken to mitigate the occurrence of neck injury in vehicle crash to reduce any adverse impact to the society in term of monetary and human life.

Previous study has proven that the activation of neck muscles can produce force which can significantly reduce head neck motion in low velocity car crash accident. In rear-end collision, under the acceleration level of 0.7g, neck active muscle is capable to generate force to reduce 30-35% of head rotations and head angular velocities (Kingma et al., 2002). Thus, in order to study the neck injury mechanism in low speed collision, the contribution of neck active muscle to overall head-neck kinematic motion has to be taken into consideration.

Changing in posture and position of head-neck segment may result in differences in force generation behavior since force output of neck muscle is depend on length of muscle and angle of joint. Previous study have found that isometric maximal neck strength is strongly correlated to rotation angles of head in flexion and extensions (Jordan et al., 1999; Suryanarayana & Kumar, 2005). It was found that neck muscle produced maximum level of force when the head-neck segment was staying at upright neutral posture. On the other hand, neck muscle force decreased when the rotation angles of head has increased. These findings suggested that the capability of neck active muscle in exerting force output may be different when head-neck segment was loaded under static and dynamic conditions. Nevertheless, the behavior of neck active muscle response under static and dynamic loading is still yet to be established.

Since neck muscle can be influential to the kinematic response of head-neck segment in low speed collision, it is critical to understand the behavior of neck muscle EMG responses before a biofidelity head-neck mathematical model can be designed. Thus, establishment of relationship between neck muscle response and head-neck response is vital to accurately predict potential neck injury in crash.

1.3 Scope of study

This study aims to determine the relationship between neck muscle activation and human head-neck kinematic response. To establish, the behavior of neck active muscle activity under three different conditions is studied. These conditions are as follows:

a) Static loading
Head-neck segment resisted against external force without making displacement from upright neutral position.
b) Dynamic loading
Head-neck segment displaced from upright neutral position to maximal range of motion while lifting an external load.
c) Low-speed frontal collision
Head-neck segment displaced from upright neutral position when subjected to low-speed frontal collision.

This study aims to determine the association of human neck muscle response between force exertion directions (for extension and flexion) and loading levels under the abovementioned loading conditions. In addition, this study also intends to determine the maximal neck muscle strength of human subjects.

1.4 Justification

Using PMHS in laboratory crash test is great to understand head-neck kinematic response in crash especially at higher velocity crash test. Nevertheless, neck active response cannot be studied in PMHS crash test. Thus, human neck muscle activation properties can only be studied through conducting low speed crash test involving human subjects.

This study aims to determine the neck muscle activation behavior in generating muscle force to resist against external forces applied to head-neck segment during low speed collision in frontal impact. It could be beneficial in providing information related to further enhance the current mathematical head-neck segment model.

To achieve this mission, human subjects are subjected to different loading conditions which are static loading, dynamic loading and low velocity crash test to determine the neck muscle activity and head neck kinematic motion in each of these loading conditions.

1.5 Objectives

The general objectives of the study are to determine neck muscle activation level and total neck muscle force produced under static loading, dynamic loading and low velocity collision. The specific objectives of the study are as followed:

a) To determine the capacity of neck muscle force under static and dynamic loading condition
b) To develop empirical models to relate generation of neck muscle force with neck muscle activation level as predictor in head flexion and extension.
c) To develop empirical model to relate neck muscle activation level with head displacement, velocity and acceleration in low velocity frontal collision.

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