In Vivo Responses of Human Subjects under Low-velocity Collision Loadings

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I. INTRODUCTION

The rules and regulations for automotive safety have been developed based on the ATD (anthropometric test dummy) rather than on a real human for many practical reasons. For durability and accessibility, the ATD is designed to be a simplified version of a human body. However, due to lack of biofidelity and diversity in anthropometry of the ATDs, the developed safety system may provide limited coverage to field accident cases [1]. Especially in the low-velocity impact situation, volunteer subjects tense their muscles to hold out against external forces and avoid impending collision [2]. Those muscle responses may reduce overall injury risk by improving ride-down, but may also increase injury risk on muscle-crossing joints due to muscle contraction forces [3]. Efforts are being made to identify the pattern and extent of muscle forces in various crash situations [4], so that a proper active human model can predict the human responses and thereby help to design advanced restraint systems applicable to real-life accidents [5].

II. METHODS

In vivo responses of human volunteers to different braking patterns during low-velocity front-end crash situations were collected and analysed through biomechanical tools. For easy access to various modalities of measurement, including contact forces, subject motion and electromyography, an automotive collision was simulated by pendulum impact on the bogie vehicle (Fig. 1). The initial height of the pendulum was adjusted to satisfy the target velocity change of the vehicle, which was 10 kph. The vehicle was designed to move along rails on four metal wheels. Two braking conditions were imposed on the vehicle: 1. the first with full braking on the four wheels, so that the vehicle slides on the rail; 2. the other without braking, so that the wheels roll free on the rail. No derailment of the vehicle occurred. External forces of a pedal and a floor on the right foot and body kinematics of five human subjects were measured through two load cells (CWW11, Dacell Inc.) and motion capture system (T-10s, Vicon Motion Systems Ltd.). The external force and marker position data were processed with low pass filter with cutoff frequency of 1,000 Hz and 6 Hz, respectively. Then, they are transformed into joint kinematics and torques through inverse dynamics (NEXUS software).

III. INITIAL FINDINGS

The peak accelerations of the sled during the front-end impact were 10.7±0.6 g and 11.4±0.5 g for the case with and without braking, respectively. The overall joint stiffnesses of knee and ankle were greater for the case with braking than without it (Fig. 2).

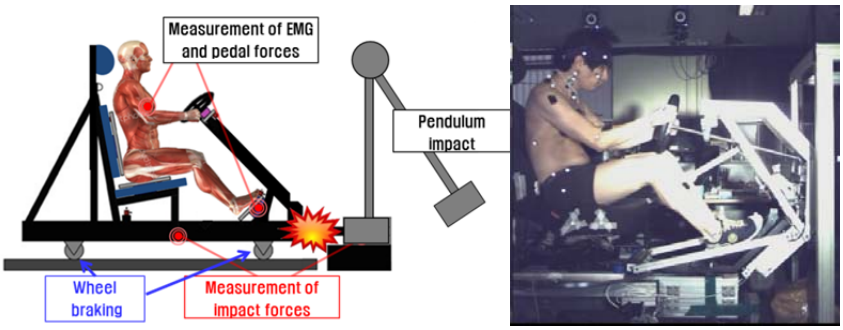

Fig. 1. Conceptual design (*left*) and snapshot (*right*) of test result with a volunteer.

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Peak joint moment at the knee and ankle were greater in the case with braking than without it. Peak joint angle were similar (knee) or greater (ankle) in the case with braking than without it. It was noted that differences in the joint stiffness between two braking cases were less at the knee than at the ankle. The joint stiffness showed 82% increase from non-braking to braking case at the knee, but 253% increase at the ankle. The maximum ankle angle reduced by 34%, and the maximum joint torque of the knee increased 38% from the case without braking compared to the case with braking.

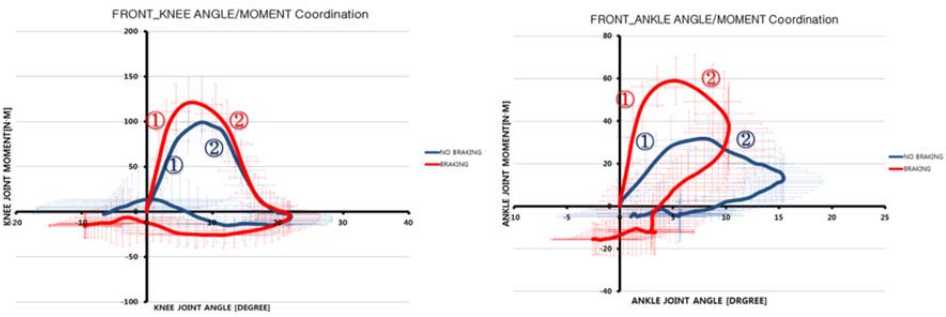

Fig. 2. Comparison of knee (*left*) and ankle (*right*) joint stiffness during different braking patterns (red: braking; blue: no braking).

Subject muscle tensing was stronger for the case with braking than without it, which was evident in smaller range of motion and higher level of muscle electromyography. Also, the pedal forces on the feet were greater for the case with braking (Fig. 3), which indicated that human subjects were more resistant to impact forces. The summed pedal and floor forces (650N with braking) are in good agreement with those from literature (700–1,000N [6]).

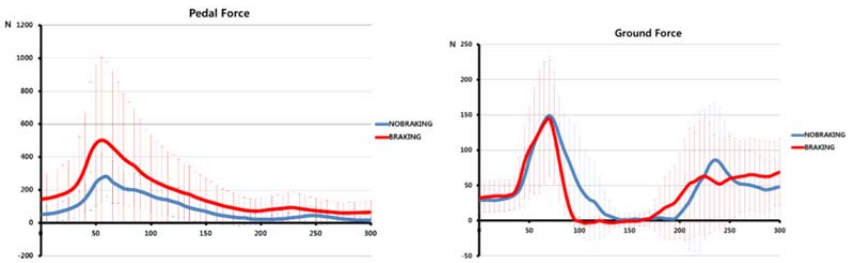

Fig. 3. Comparison of pedal (*left*) and floor forces (*right*) during different braking patterns (red: braking; blue: no braking).

IV. DISCUSSION

The sled acceleration data show that the transmitted impact forces from the pendulum to the sled were larger for the case with braking than without it. Since there was no seatbelt in the sled to hold back the subject body, subjects would have experienced the impact forces more drastically than in a normal vehicle with a seatbelt. Greater pedal reaction forces resulted in higher stiffness in the braking case, which may in turn result in more controlled body kinematics but may also increase joint loadings, with bony fracture and disruption of soft tissues for a given amount of impact loadings. Temporary release of braking at the moment of impact may resolve the soft tissue injuries from high muscle tensing for low velocity impact. Also, investigation of in vivo muscle tensing during the low-velocity impact with various vehicular braking patterns is warranted.

V. REFERENCES

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