Investigation of Active Muscle Response on the Occupant-Knee Airbag Interaction in Frontal Impacts

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I. INTRODUCTION

Knee airbags (KABs) have been implemented as one countermeasure to reduce potential occupant lower extremity injuries. Recent field data analysis suggests that femur and pelvis injuries are reduced in the presence of a deployed KAB, but the data also suggested that foot, ankle and leg injuries may increase [1-2]. It has been demonstrated that tibia loads will increase for out-of-position occupants interacting with a deploying KAB, and that the ensuing kinematics are highly sensitive to the initial position of the lower extremities relative to the KAB [3]. This study builds on previous work by exploring how the active muscle response of the occupant may influence the loading and kinematics of the lower extremities during a KAB deployment.

II. METHODS

A finite element (FE) human body model (HBM) in a seated driving position (Academic THUMS Version 4.0.1 for LS-Dyna) was modified to include the active muscle response of the lower extremities (Fig. 1 (a)). 32 muscle groups were added to the HBM using 1D elements with a Hill-type active muscle constitutive model [4]. Origin, insertion points and physiological cross-sectional area of the muscles were identified based on the data reported in the literature [5]. Parameters for the Hill-type constitutive model were determined from an OpenSim 3-D musculoskeletal model [6], and the activation level for each muscle during an emergency braking action was calculated using an inverse dynamics procedure. The HBM predicted a peak pedal force of 700 N with two-foot bracing in a static posture, which was in accordance with the reported volunteer tests [7] (Fig. 1b). Active muscle response in the HBM was implemented to produce three actions: passive (no activation), braking (active on the right lower extremity only), and bracing (active on both lower extremities).

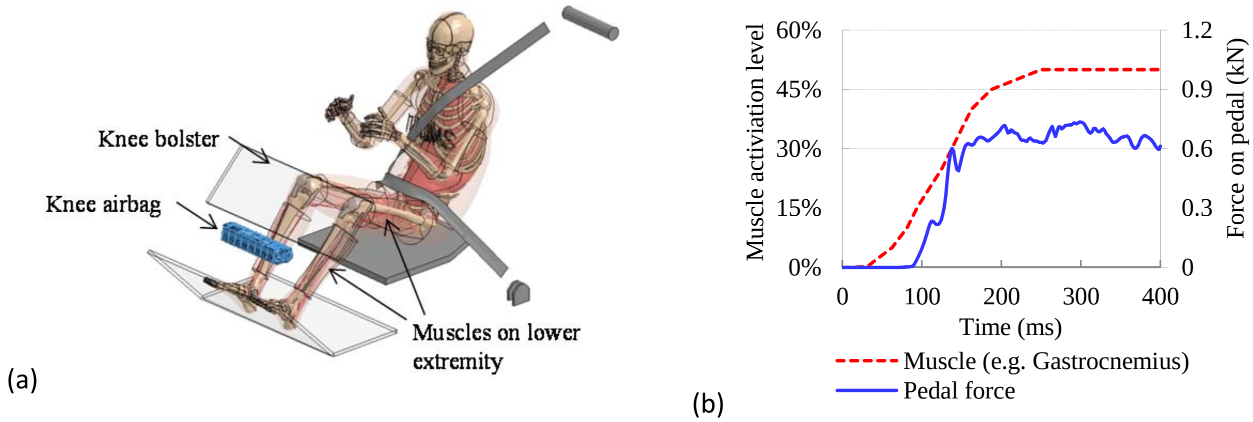

Fig. 1. (a) Model set-up, (b) time histories of muscle activation level (e.g. Gastrocnemius) and pedal force.

Simulation cases with the modified HBM were conducted in the frontal impact scenarios in a simplified vehicle interior (Fig. 1 (a)) with a bottom-deployed KAB. The vehicle geometry was based on the Gold Standard frontal crash buck (no driver airbag), with rigid parts (seat, knee bolster and floor) and a non-load limiting seatbelt without pre-tensioner. A full-factorial simulation matrix was performed with the following variables: KAB standoff to knee (120 mm/60 mm), muscle response (passive/braking/bracing) and vehicle condition (static/40 mph frontal impact). The corpuscular particle method was used to simulate the dynamics of the unfolding and inflating of the KAB. Force and bending moments were extracted from the middle of the femur

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and the distal third of the tibia. Tibia injury risk was assessed using the Revised Tibia Index (RTI) [8]. A general linear model was used to assess factor significance.

III. INITIAL FINDINGS

The simulation results indicated that muscle activation had a statistically significant effect ($p<0.05$) on increasing the internal forces and moments of the lower extremities, regardless of loading scenario (Table I), with the driver right lower extremity experiencing slightly higher loads than the left. Muscle activation resulted in increasing the maximum axial force and resultant bending moment of the driver right femur (3.0±0.4 kN and 67±10 Nm) and right tibia (1.7±0.3 kN and 40±9 Nm) over all loading scenarios, and raised the RTI by 0.31±0.03 and 0.18±0.06 for the right and left tibia, respectively. The dynamic impact condition increased the tibia and femur forces (0.9±0.3 kN and 0.9±0.5 kN) and moments (17±12 Nm and 45±12 Nm) relative to the static vehicle condition ($p<0.10$). The inertial effect increased the RTI in both tibias by 0.15±0.05. Finally, decreasing the KAB standoff resulted in significant increases in right tibia force and moment (0.5±0.2 kN and 40±7 Nm), resulting in an average increase in RTI of 0.23±0.05 for both lower extremities. Femur moment also significantly increased (37±8 Nm for right side), but femur axial force was not significant for KAB standoff.

There were noticeable differences in occupant kinematics with changes in the loading scenario. With the driver forward 60 mm, the KAB tended to contact the lower extremity earlier during the deployment phase and led to approximately 30° greater abduction of the lower extremities. However, the effect of muscle activation did not substantially change the occupant kinematics in either the dynamic or static conditions.

TABLE I

COMPARISON OF THE MAXIMUM LOADS ON LOWER EXTREMITIES IN THE SIMULATION MATRIX

Simulation Matrix				Femur				Tibia					
				Axial force (kN)		Bending moment (Nm)		Axial force (kN)		Bending moment (Nm)		Revised Tibia Index (RTI)	
No.	Vehicle condition	KAB Stand-off	Muscle response	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
1	Dynamic	Normal	Bracing	4.41	4.68	110.66	102.09	2.43	2.37	76.01	82.71	0.52	0.54
2			Braking	4.34	2.64	107.84	83.06	2.45	1.22	82.74	77.19	0.55	0.42
3			Passive	1.90	2.10	50.77	61.99	0.54	0.68	62.24	46.79	0.30	0.25
4		Forward	Bracing	5.01	4.14	162.22	110.61	3.11	3.43	128.63	102.37	0.79	0.71
5			Braking	4.15	2.55	170.09	132.10	3.57	2.03	110.89	91.02	0.76	0.55
6			Passive	2.40	1.29	101.27	83.03	1.57	1.53	70.62	69.05	0.43	0.42
7	Static	Normal	Bracing	4.02	4.03	78.50	80.11	1.66	1.59	54.45	58.54	0.37	0.38
8			Braking	4.40	0.22	88.62	37.80	1.93	0.20	70.87	8.43	0.46	0.05
9			Passive	0.20	0.14	15.99	11.99	0.19	0.12	20.78	15.84	0.10	0.08
10		Forward	Bracing	4.44	4.41	116.32	103.52	1.31	2.38	122.09	113.48	0.62	0.67
11			Braking	4.54	0.89	97.08	51.15	1.88	2.12	111.96	92.20	0.62	0.56
12			Passive	0.92	0.89	25.84	28.38	0.64	0.67	61.36	62.64	0.31	0.32

IV. DISCUSSION

These results are part of a preliminary study focused on identifying the potential for the lower extremity injury to occupants in real-world crashes in the presence of KAB deployment. The current study utilised a simplified vehicle model that represented a "worst case" environment for evaluating the occupant's interaction with the KAB. Active muscle response contributed a substantial portion of the loading on the lower extremities, which can be interpreted by the increased effective body mass and axial compression along the femur/tibia shaft, and the pre-impact posture due to the muscle contraction. Additional KAB designs and alternative impact conditions will be included in the future studies to provide a broader picture on the efficacy of KABs.

V. ACKNOWLEDGEMENTS

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