Effect of the Lower Limb Muscles on the Knee Lateral Bending and Medial Collateral Ligament's Elongation during Vehicle – Pedestrian Impacts

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I. INTRODUCTION

The tools and thresholds used for vehicle safety assessments are largely governed by experiments performed under controlled laboratory conditions. The experiments performed using post-mortem human subjects (PMHSs), imitating the interaction between a vehicle and a pedestrian, provide significant information about the injury type, severity, and mechanism. Even though this data is essential for developing and/or validating pedestrian dummies/impactors, and computational human body models (HBMs), they can be misinterpreted and must be reviewed along with the real-life accident data. For instance, a recent study [1] reported whole-body PMHS tests with different types of representative vehicle shapes, observed a large number (around 90 %) of Medial Collateral Ligament (MCL) injuries. Previous studies [2] also noted a large number of MCL injuries in whole-body pedestrian-vehicle impact studies with PMHSs. However, the analysis of various accident databases [2-4] suggests, that the MCL during rea-life accidents is not injured as frequently as in laboratory experiments. Though the fact that the ligament injuries are diagnosed sometime later than the actual event [4], the ratio of MCL injuries observed in laboratory experiments to during real-life crashes is considerably high. Among the parameters, which could possibly explain this difference, the muscle contractions have been suspected to have a relevant role in reducing the injury to the knee ligaments [2][5]. The present study investigated the effect of muscle contractions on MCL elongation and knee lateral bending, using a posture that produces a response analogous to the response of leg form impactors like the Advanced Pedestrian Legform Impactor (aPLI). The simulations were performed with four different types of vehicle fronts.

II. METHODS

In the present study, all simulations were performed using the Explicit Finite Element Solver Visual Performance Solution (VPS version 2019), ESI group). The biomechanical data used in the manuscript was adapted from peer reviewed published literature .

Active HBM

The THUMS AM50 v4.02 pedestrian model was enhanced by adding all major muscles (1D elements) from pelvis to toes as described in previous studies [6-7]. To check if addition of muscles causes any anomalies while they are in passive state, a HBM with passive muscles (zero activation) was simulated and compared with the published experimental results for three types of representative vehicles [1].

Posture Selection and Boundary Conditions

The HBM was positioned similar to the posture in [8-9]. This posture not only produces a higher MCL elongation compared to the walking postures used in previous studies [5] and recommendations [10], but also produces a lower extremity response, analogous to the aPLI response [9]. To investigate the effect of active muscles, simulations were performed using two HBM models (1) without muscles and (2) active, and four types of Generic Vehicle (GV) [11] models: (a) Family Car (FCR) (b) Roadster (RDS) (c) Multi-purpose Vehicle (MPV) and (d) Sports Utility Vehicle (SUV). For all simulations, the vehicle impacted HBM laterally, at a speed of 40 km/h. The MCL elongation was measured as the linear distance between the attachment points to make it consitent with the method used for the aPLI. The knee lateral bending was measured as an angle between corresponding axes of coordinate systems attached to the femur and the tibia.

In active state, for each muscle of a limb, specific activation level is necessary. As the data for all muscles were not available from a single source, activation levels were adapted from various studies like [12-13]. The impacting leg resembles mid-stance posture bearing complete weight of the pedestrian. The muscle activation levels were chosen corresponding to equivalent phase of the gait cycle [12 - 13]. The activation levels were assumed constant during the simulation.

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III. INITIAL FINDINGS

For the model with passive muscles, good agreement was observed for the HBM kinematics and contact force data, between the simulation results and experimental data [1]. The initial results of this study focus on the MCL elongations as they can be readily compared with the corresponding responses of the aPLI. The knee lateral bending was also tracked during the simulations to understand its effect on MCL elongation. A comparison of the MCL elongation as well as the knee lateral bending of the model with passive muscles and the active model is shown in Fig. 1. It can be observed that for all types of vehicles, knee lateral bending as well as the MCL elongation reduced in the active model compared to the model without muscles. The MCL elongation reduced from 5% to 20 % (average around 10%) and knee lateral bending reduced 9% to 13 %.

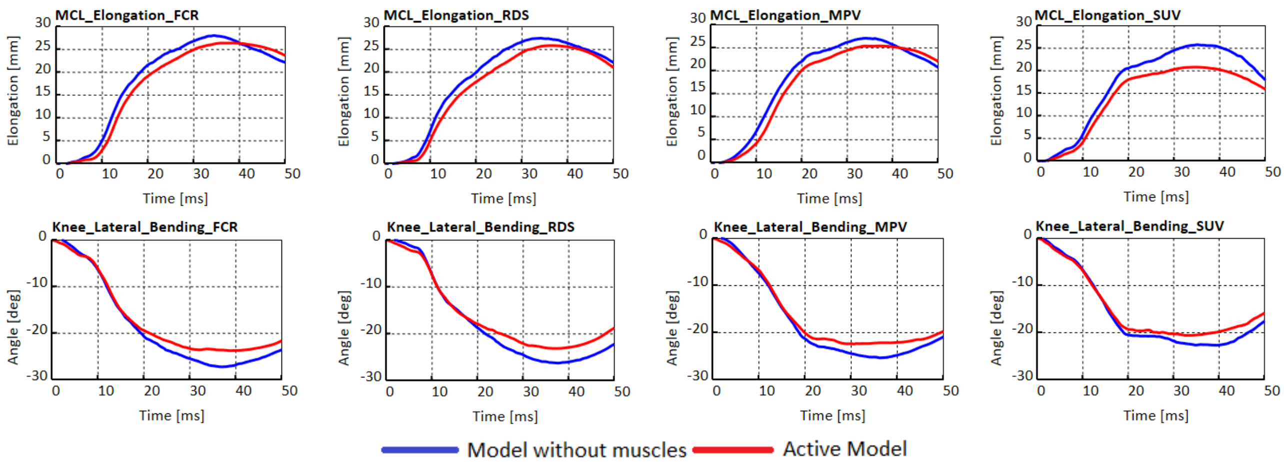

Fig. 1. MCL Elongations and Knee Lateral Bendings for different Generic Vehicles

IV. DISCUSSION

Current systems for the vehicle safety evaluation use legform impactors. In addition to other parameters, leg form impactors like aPLI, measures MCL elongations which are then used to assess the resulting injuries during an impact. However, the legform impactors have been validated against PMHS experiments [8] and may not account for the muscle contractions directly. The present study offers an evaluation of the effect of active muscles in a posture that produces lower extremity response, analogous to the response of aPLI. The results of the study are in agreement with previous findings reporting similar effect for a different posture and vehicle [5]. Unlike previous studies [5], the ligament failures have not been activated, and hence ligament elongations were tracked through the entire simulation for better comparison with leg form impactor data.

The model in the present study included muscles only from pelvis to toes. However, the authors believe, that inclusion of the remaining muscles would not affect the knee joint kinematics largely. The posture used in the study does not correspond to any stage of the standard gait cycle but resembles mid-stance. Hence, the activation levels corresponding to the nearly mid-stance phase could only be adapted. Moreover, the activation data was compiled from different studies as not all data was available from a single source.

The simulation conditions used in the present study, leads to results analogus to the results predicted by aPLI [9]. Hence, the authors would like to emphasise upon considering the effect of active muscles as one of the factors in reducing the knee ligament elongations and lateral bending, for defining the thresholds for leg form impactors such as aPLI. In future, other parameters (viz. pedestrian posture and state at the time of impact, and vehicle speed) may be considered to strengthen the outcomes and reported results.

V. REFERENCES

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