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Effect of Contact Friction between Seatbelt and Human Body Model on Simulation of Rib Fracture in Frontal Impact

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Abstract:

Background: Thorax injury is the second cause of the death in the vehicle collision and seatbelt is the major restraint system for thorax protection. Seatbelt contact friction coefficient may have some influence on chest injury prediction because it can affect the position of the seatbelt during the impact.

Objective: The objective is to study the influence of the seatbelt contact friction coefficient on predicted rib fracture outcome in frontal impact with full frontal collision simulation.

Method and Material: Four simulations of frontal impact sled tests in the same environment were conducted wherein the contact friction coefficient between the seatbelt and the chest model was varied. The fracture possibilities of all the twenty-four ribs were calculated with the probabilistic method using strain-fracture criteria developed by the statistical analysis of rib fracture tests. The rib fracture results can show by possibility numbers (between 0 to 1) in which all the small changes of the chest injury can show with the change of the possibilities.

Results: A noticeable effect was observed wherein increasing friction coefficient which tended to cause a slight decrease in the number of predicted fractures.

Conclusions: Despite this, the magnitude of sensitivity is small, suggesting that in the absence of other information arbitrary values of friction coefficient within a reasonable intermediate range may be justified for this specific test condition. The contact friction coefficient should also be carefully concerned when carrying out the chest injury study with seatbelt.

Keywords: Biomechanics, Thorax injury, Simulation, Contact friction, Seatbelt

1 Introduction

Rib fracture is one of the most common types of injury to belted automobile occupants that are involved in frontal collisions. With the increasing age, the bone mineral density, cortical bone thickness, and characteristics of the rib will change, making the ribs more susceptible to fracture. As a result, older people are prone to serious chest injury during automobile collisions [1], [2].

Human body finite element models may provide a tool for predicting rib fracture injury risk in simulated automobile collisions, facilitating the development and evaluation of potential countermeasures. Such models, however, rely on an accurate representation of the interaction between the seatbelt and the chest. One of the characteristics that affects this interaction is the friction coefficient between the seatbelt and the chest. The contact friction coefficient affects the ability of the shoulder belt to slide across the chest, changing its position over-top of the ribcage. The friction coefficient also affects the magnitude of the shear force that may be applied to the chest by the belt. Unfortunately, the contact friction between a seatbelt and the chest is difficult to quantify, and is thus currently not quantified.

The goal of this study was to perform a modeling sensitivity to observe the effect of the seatbelt friction coefficient characteristics on predicted rib fracture risk in simulated frontal collisions with a belted occupant.

2 Methods

2.1 Simulation Condition

Frontal-impact simulations were performed that were based on the sled test conditions described by Shaw et al. (**Figure 1**). That study tested Post Mortem Human Surrogates (PMHS) in 40 km/h frontal impacts on a servo-controlled impact sled [3]. This test condition utilizes a simplified test environment developed by the Center for Applied Biomechanics (CAB). In order to put the test subjects under the same or comparable conditions, the cadavers were settled in such a position that each subject was fixed in a pre-impact position approximating that of the standard occupant position [4].

The test subjects were settled on a flat rigid seat and supported by a system including, knee bolster, footrest and back support. All the experiments and the simulations were in nearly the same deceleration pulse. The mechanical characteristics of the seatbelt were obtained via elongation testing. The restraint webbing was manufactured by Narricut (6-8% elongation, 26.7 kN minimum tensile strength).

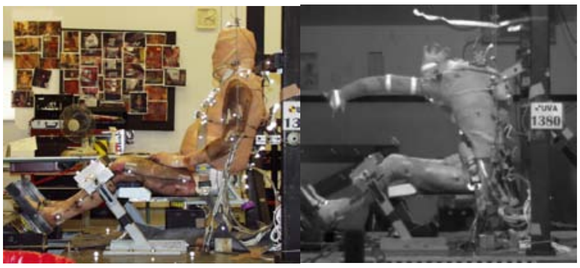

Figure 1:Initial position (left), and video capture at the time of maximum forward head excursion (right) from one of the tests that formed the basis for these simulations.

2.2 Human Body Model

The 50th percentile male GHBMC version 4.2 (GHBMC V4.2) was adopted in this study as the Human Body Model (HBM). After the development, some verification work has been done [5], [6] to this model.

2.3 Probabilistic Rib Fracture Prediction Method

The method used seeks to identify the probability of fracture in each rib, based on a material-level injury risk function consisting of a cumulative distribution of rib cortical bone ultimate strains observed in a sample population [7]. In this case, the peak 1st principal strain in each rib was compared to the ultimate strain distribution adjusted to represent a 55-year-old to predict the risk of fracture in each rib for that age of occupant. For this analysis, simulations were executed with the element elimination functionality disabled.

2.4 Simulation Matrix

A total of four simulations were conducted. Four separate frictions, 0.2 apart, were simulated and studied (**Table 1**).

Table 1 : Simulation matrix

Simulation ID	*Friction coefficient*
Simulation 1	*0.0*
Simulation 2	*0.2*
Simulation 3	*0.4*
Simulation 4	*0.6*

3 Results

Table 2 : Predicted probability of fracture in each rib by friction coefficient value (predicted for age 55).

Rib	***Simulation 1 (Fri=0.0)***		***Simulation 2 (Fri=0.2)***		***Simulation 3 (Fri=0.4)***		***Simulation 4 (Fri=0.6)***	
	left	***right***	***left***	***right***	***left***	***right***	***left***	***right***
1	1	0.5	1	0.5	1	0.4167	1	0.4167
2	0	0	0	0.0833	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	1	0	0.8333	0	0.4167	0	0
5	0	0	0	0	0	0	0	0
6	1	1	1	0.4167	1	0	1	0
7	1	1	1	0.8333	1	0.4167	1	0.4167
8	0.4167	1	1	1	1	1	1	1

9	1	1	1	1	1	1	1	0.8333
10	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1
12	0	0	0	0	0	0	0	0

To name all the ribs, characters L and R are applied to represent left and right side of ribcage. The number followed these characters mean the rib number. For example, L4 means the rib number 4 in the left side of ribcage.

The probabilities of rib fracture predicted for each simulation are included in **Table 2**. Going from a friction coefficient value of 0 to a value of 0.6 substantially changed the fracture probabilities in four ribs (L8, R4, R6, and R7). Transitioning between intermediate values exhibited an even more subtle difference. During the simulation of the low friction coefficient (friction coefficient 0.0 or 0.2), the kinematics are nearly the same and there is an obvious slide of the seatbelt. While for the high friction coefficient (friction coefficient 0.6), the contact flesh was twisted due to interaction with the seatbelt.

The change of fracture possibilities will represent the seatbelt slide trend. From the test's results [3], the seatbelt may slide and go upward due to the small contact friction coefficient or other unknown reasons during the impact. And this seatbelt change is also recognized.

If the contact friction coefficient was large (friction coefficient 0.6), which represent the possibility of the seatbelt slide will be very small, most of the fractures happen in the lower ribcage (rib 6 to rib 11). However, if the contact friction coefficient becomes smaller, the seatbelt will possibly slide. In consequence, the seatbelt will go upward along the thorax. As a result, the rib fracture possibilities in the upper ribcage (rib 1 to rib 6) will rise.

It is indicated from the rib fracture possibility comparison between both sides of the ribcage that the right side is more sensitive to the contact friction. However, in terms of calculating only the left-side rib fractures in this study, there is no change of the rib fractures among the four simulations except a slight change in L8 under the small contact frictions. As a contrast, most of the rib fracture possibilities from the right side will change with the alteration of the contact friction, and most of the changes are not negligible. All the possibility changes in the right side happen in all the four simulations no matter of the magnitude of friction coefficients, whereas the changes in the left side happen only under the small friction.

The possibility responses may also indicate the change of chest deflections, because the R4, L4, R7 and L7 are the mounted locations of the chest deflection measurement points both in the cadaver tests and simulations. All these four locations are defined at the same position of The Test Device for Human Occupant Restraint (THOR) dummy. The fracture possibility goes down in the R4 (changes from 1 to 0). This means this rib will definitely fracture with the prediction method under the friction coefficient 0.0. However, when the friction coefficient is increased to 0.6, the fracture possibility would fall down to 0 (no fracture predicted in this rib). This kind of obvious drop also happened in the right rib 7 (from 1 to 0.4167), though the decrease is not as dramatic as in the R4. The fracture change means the ribcage stiffness loss will be different. As a result, this loss may affect the chest deflection.

R1 and L1 are at risk of fracture, though there is a slight fracture possibility decrease in the R1 with the increase of the contact friction. The peak strain of L1 in four simulations are all beyond the fracture criterion. It is noticed that because the simulation position is the occupant position, the right side will directly contact (be compressed) the HBM thorax, and the left side is on the opposite side of the contact. Therefore, the cause of this fracture may not be the compression of seatbelt.

The R10, L10, R11 and L11 are all fractured in the four simulations according to the results of **Table 2**, which means these four ribs are all in risk of fracture no matter of the slide magnitude of the seatbelt. The reason may be the direct contact between this area and the seatbelt. In most of the traffic crash injuries, ribs 11 and 12 are rarely fractured, because they are floating and connected to the ribcage only by soft tissue. Furthermore, the injury possibility analyzed from the crash data of rib 10 is also quite low.

It is concluded from the table that the lower ribcage is more sensitive than the upper ribcage. No matter of the magnitude of the contact friction, rib 7 to 11 are always in risk of fracture, and the rib 1 in both sides are also in the dangerous situation with the defined simulation condition. The lower left side is the contact area between the seatbelt and the thorax. The compression may be the reason of the fracture for the left side ribs. As the opposite side of the contact area, the fracture happened in the lower right ribcage, and what was demonstrated from the simulation is the peak strains of the ribs here are all beyond the criteria defined in the prediction method.

4 Discussion and Conclusions

With the increase of the age, the ribs will become more fragile to fracture, which means rib fracture possibility will increase. And all the simulations are applied at the age of 55, which is nearly the average age of the eight tests subjects [3]. That is the reason why so many fractures calculated in the simulations. Usually, the targeted group focused in the crash is younger. With the increase of age, the ribcage will change, and the common trend is the position of the ribs will become lower. As a result, the contact ribs with the same seatbelt will be different at different ages. The influence of age is taken roughly into account in this prediction method regardless of the shape.

The body shape may affect the injury outcome, which means the shape of the HBM will cause some errors in the injury outcomes. The GHBMC model is constructed with the average body shape (50^{th} percentile male) for human beings. Although it is unsuitable for an individual case considering the weight, height and gender, the HBM used here can give a rough view of the chest injury.

Altering the contact friction coefficient between the shoulder belt and the chest had a small, but noticeable effect on the probabilities of rib fracture predicted with the simulations. Increasing the friction coefficient tended to decrease the number of rib fractures predicted, where increasing from a friction coefficient value of zero to 0.6 reduced the number of fracture from approx. 14 to approx. 12. While the exact mechanism of this difference is currently unknown, factors that may have contributed may include slip of the belt changing the belt path, a difference in the proportion of the restraining load being borne by shear in the superficial tissue, or increased grip on the stiffer structures of the upper thorax.

Care should be taken, however when extrapolating this result as friction coefficient may have a greater effect in other simulation scenarios. Ideally, the development of simulations of other test conditions should always include sensitivity analyses on friction coefficient and other unknown boundary characteristics quantities similar to that performed here to quantify the potential error associated with uncertainties in these values.

For practical purposes, contact friction coefficient around 0.4 is better to use when carrying out the simulation in the sled frontal impact at 40 km/h due to the constraint of the seatbelt. The results of this study suggested that small changes in friction coefficient will have minimal effect on predicted injury outcome.

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