MECHANISM OF REDUCING THORACIC DEFLECTIONS AND RIB STRAINS USING SUPPLEMENTAL SHOULDER BELTS DURING FRONTAL IMPACTS

Ola Bostrom
Autoliv Research
Sweden
Yasuki Motozawa
Honda R&D
Japan
Shinsuke Oda
Autoliv
Japan
Yuichi Ito
Honda R&D
Japan
Krystoffer Mroz
Autoliv Research
Sweden

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ABSTRACT

With an ageing population with increased needs of mobility, special attention to the safety of senior car occupants is becoming more important. As seniors in fatal crashes primarily die of chest injuries there is need of understanding how to reduce the risk of rib fractures. Recently new types of belts have been introduced on the market including inflatable and supplemental.

It has been suggested, one key to protect more ribs in frontal impacts is by optimizing the force distribution. In this study the role of kinematics or more specifically the orientation of the torso in relation to the belt loading, is evaluated.

The aim of this paper was to further understand the protection role of a supplementary belt. The hypothesis was that the upper body rotation, the twisting of the torso is critical in saving ribs. We conducted simulated frontal tests in three configurations by using a human FE model (THUMS) representative of an American 50 percentile male adult. The three configurations were a reference 4 kN three point belt and a driver airbag, an added 1 kN two point shoulder belt restraining the shoulder not restrained by the three point belt (the single) and two added 0.5 kN two point belts restraining each shoulder (the double).We compared the kinematics of the upper torso with the chest deflections and rib strains.

Adding a 1 kN belt load, single or double, resulted in reduced chest deflection and excursion as well as rib strain. The single belt as opposed to the double reduced the upper body rotation considerably. The greatest chest deflection reductions were found at the lower part of the chest for the single belt and at the upper for the double.

As a conclusion, the kinematics of the occupant may contribute to the loading on the chest. The paper is relevant for understanding how to optimize belt systems for minimal occupant loading and excursion.

INTRODUCTION

The three point belt is doubtless a practical way to distribute the restraining forces on the occupant body during a frontal impact. Not only is the usage rate high, 97.5% in European cars with seat belt reminders according to Lie et al [2008], the overall lifesaving effectiveness is also high (61% according to Cummings et al [2003]). Still the performance can be enhanced. While belt load limiters and pretensioners have become more or less a standard for the front seats, four-point belts in the form of a V have been suggested and evaluated by Rouhana et al [2003]. Moreover inflatable belts have been introduced in Ford Explorer, Lexus LFA and this year in Mercedes S-class ; although they are intended to enhance the performance in conventional three-points seatbelts geometry, their implementation is currently limited due to the complexity of the system. Also, four point belts in the form of a supplementary belt have been introduced in the Renault Twizy. The extra belt sometimes called the rucksack belt was first described by Bostrom et al [2008]. The belt was shown to have a considerable protective effect in far side impacts and rollovers.

The protective effect of belt force limiting and pretensioning, V-shaped four point belt and inflatable shoulder part of the belt have been proved by means of PHMS in particular types of frontal impacts [Forman et al 2009, Rouhana et al 2003]. It has been suggested that by distributing the forces on a larger area and engaging additional bony structures such as the other clavicle, the load on the ribs is reduced in general.

Rib fractures after a car crash are not necessarily life threatening. However, the situation for seniors (elderly) is different compared to the younger. When young people tend to die from head injuries seniors tend to die from chest injuries [Kent et al 2005]. According to a study by Kent et al [2008] seniors ending up at a hospital after a car crash may die from only a few rib fractures. As the ageing population and requirements of mobility is increasing around the world, rib fracture countermeasures for seniors are becoming more and more important.

In this paper a new hypothesis of rib fracture reduction, the twisting theory, is suggested and tested in a simplified way. During a frontal impact the thorax is twisting and thereby changing the load distribution and the direction. The twisting hypothesis can be formulated such that reduction of twisting is beneficial regarding braking of ribs.

The aim of this paper was to further understand the protection role of a supplementary belt. More specifically, the aim was to understand the importance of changed kinematics versus changed force distribution. The method used was numerical human body model simulations.

METHOD

The set-up of the simulations is described in detail by Mroz et al [2010]. The crash pulse used was a 56km/h full frontal (USNCAP 2006 Honda Civic). The mid-sized male human body model THUMS [Iwamoto et al. 2002] was used as the occupant on the driver side of a generic vehicle interior model of typical mid-sized sedan. For this study the material model of the THUMS rib cortical bone was simplified by using an elasto-plastic material model without any fracture failure criterion and strain-rate dependency. The total number of elements for this modified version of THUMS was app. 158000.

The occupant was, as a reference, restrained by a three point pretensioned belt with a 4 kN load limiter and a symmetric driver airbag. In addition to the 1) reference configuration simulations were performed with 2) a supplemental two-point belt with a 1 kN load limiting and 3) two symmetrical two-point belts with each 0,5 kN load limiting levels. The supplemental belts were not pretensioned.

Torso twisting was analyzed by calculating the rotation of a thought line between the shoulder blades, see Figure 1.

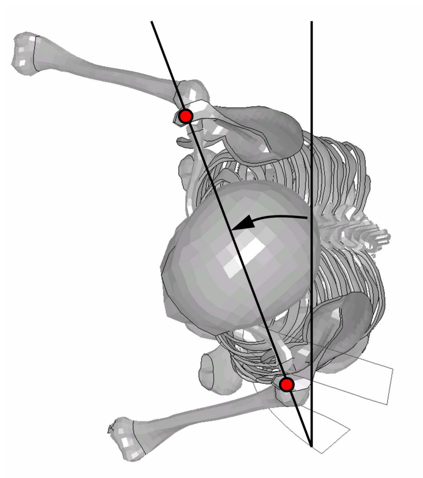

Figure 1 – Twisting of the torso was analyzed by calculating the rotation of a line through the shoulder blades.

To evaluate the risk of rib fractures, chest deflections and rib strains were chosen as measurements. Chest deflections were measured at mid-sternum and at left and right hand side of the ribs 3 to 7. See Figure 2. Regarding rib strain, the strain levels were divided into the discrete values of 0, 0.5, 1, 1.5, 2% and so on. If at least one element on a rib exceeded say 1% but not 1.5% the rib was considered as a rib with rib strain 1%.

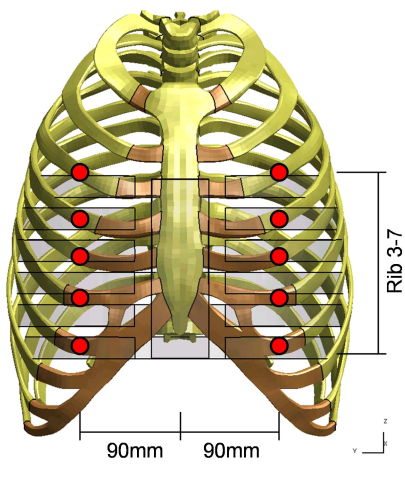

Figure 2. The location of the 11 points where chest deflections were evaluated.

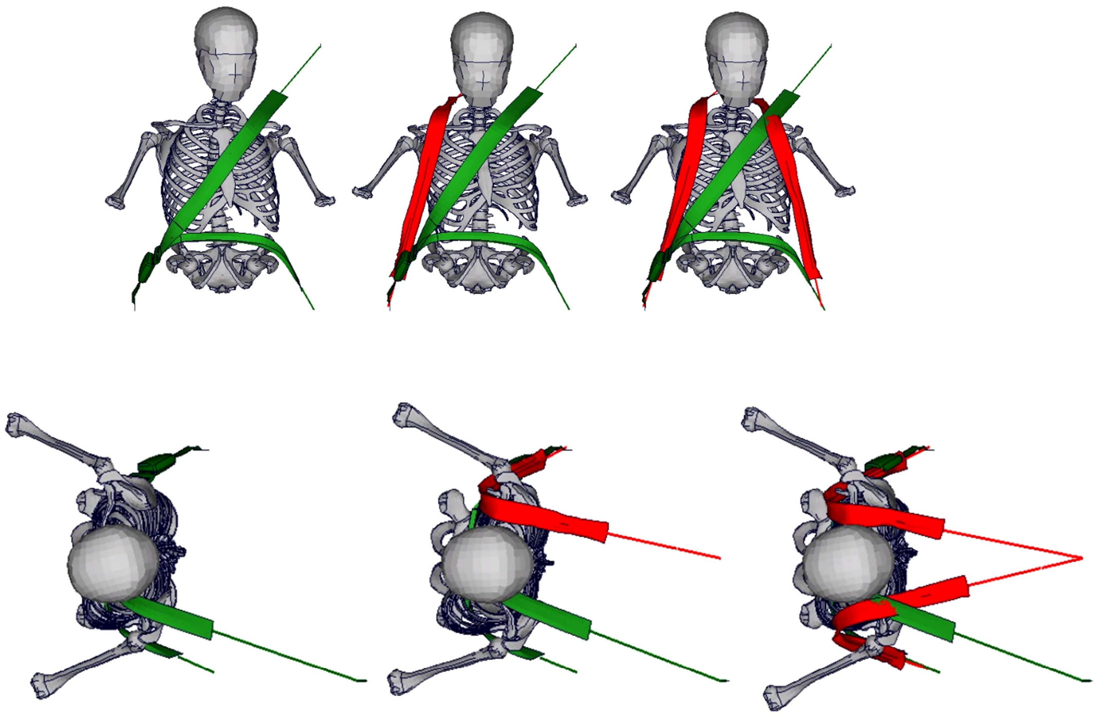

Figure 3. Front and top view, 80 ms into a 56km/h full frontal frontal impact for the three belt configurations.

RESULTS

Adding 1 kN of belt load resulted in 36 (single) and 35 (double) mm less peak chest excursion (279 compared to 242 and 243 mm). In addition the upper body rotation (the twisting), the mid sternum chest deflection and the rib strain decreased.

The top and side views 80 ms into the crash are shown in Figure 3.

The upper body rotation, the torso twisting, during the impact is shown in Figure 4.

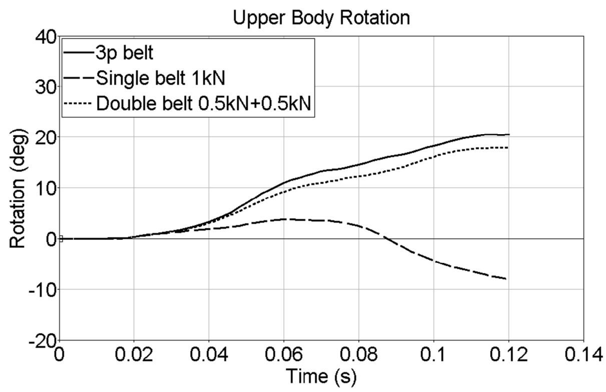

Figure 4 The upper body rotation, or torso twisting, for the three configurations during the impact.

The mid-sternum deflections are shown in Figure 5. The lowest deflections were obtained for the single followed by the double extra belts.

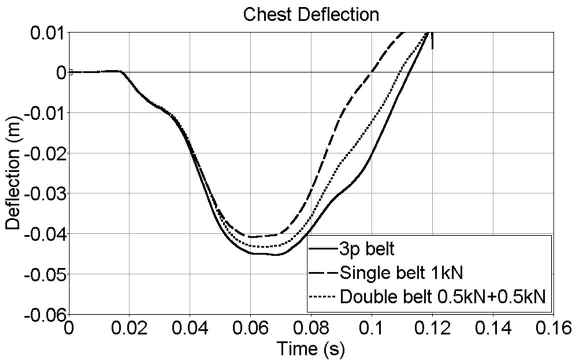

Figure 5. Mid sternum chest deflection for the three configurations.

The distribution of the peak chest deflections for the 5 left and right locations are shown in Figure 6. The deflections follow the belt route with the highest deflections in the lower part of the thorax. The greatest reduction was found at rib level 7 for the single belt and at rib level 3 for the double belt.

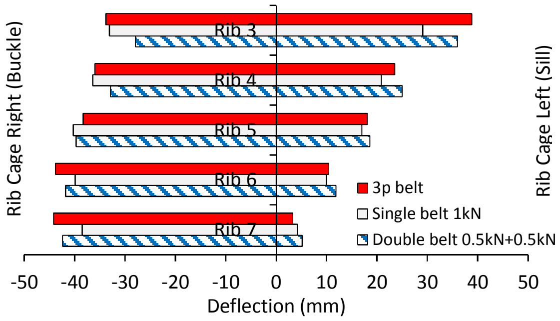

Figure 6. Distribution of the chest deflection at the 5 right and 5 left locations defined in Figure 2.

The strain distribution is shown in Figure 7. For levels up to 3% the added belts produced the smallest strains.

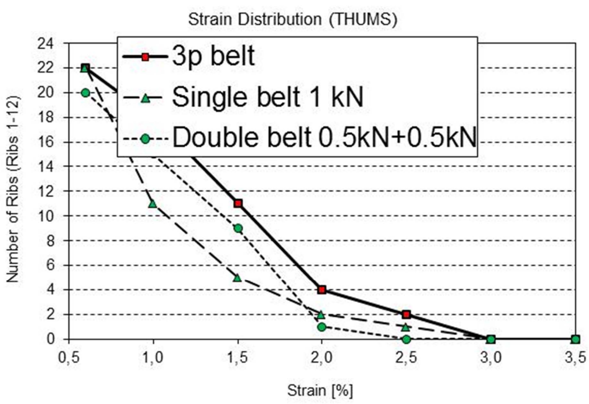

Figure 7. Number of ribs with the discrete values of 0, 0.5%, 1% and so on for the three configurations.

DISCUSSION

Previous studies have shown that blunt loading is more effective than belt loading. It has been explained as an effect of distribution i.e. reduction of pressure on the thorax. Recently a supplemental shoulder belt system was proposed to enhance chest protection. In the present study, we focused on the mechanism of its effect. Major limitations are the unpractical (however theoretically ideal) usage of the double belt configuration as well as the usage of chest deflection and rib strain as indicators of rib fractures.

According to the results of this paper, reducing the twisting of the torso by restraining the shoulder not directly restrained by the three point belt, does reduce chest excursion and deflection and rib strain. By distributing the extra load of 1 kN on both shoulders (0.5 kN on each) the twisting is more or less the same as without extra belts and still the chest excursion and deflection and rib strain is reduced. That is reducing the twisting seems related to reduction of chest load (in terms of deflection and rib strain) however not necessarily.

In a recent paper, Forman et al [2012] described a causal probabilistic framework to predict rib fracture risk based on strains observed in human-body FE models. Distribution of crash speeds, critical rib strain levels and known age dependent risks of dying due to rib fractures were used in order to evaluate differences between restraint systems. This framework, although beneficial for the present purpose, was not used in this study.

In the present study the ribs of the THUMS were not allowed to fracture. The greatest reduction, thanks to the extra belts, occurred for levels of around 1.5%. Five ribs had strain levels above 1.5% for the single belt. The double belt reduced the chest deflection in the upper part of the thorax while the single in the lower part. In order to further understand the role of the twisting a fracture model need to be incorporated.

CONCLUSION

The consequence of adding two types of extra belt, the single and the double, to a human body model (THUMS) restrained by a 4 kN three point belt and a driver airbag in a 56 km/h full frontal crash test was evaluated in this study. The two types of extra belts were designed to distribute the force on the chest differently. Adding a 1 kN belt load, single or double, resulted in lower chest deflection and excursion as well as rib strain. The single belt as opposed to the double reduced the upper body rotation considerably. The greatest chest deflection reductions were found at the lower part of the chest for the single belt and at the upper for the double.

As a conclusion, the kinematics of the occupant may contribute to the load of the chest. The paper is relevant for understanding how to optimize belt systems for minimal occupant loading and excursion.

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