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MODELING AND ANALYSIS OF KNEE - DASHBOARD IMPACT IN FRONTAL COLLISION

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Abstract**—** During the frontal collision of a vehicle, be it with another vehicle or with a fixed or mobile obstacle, one of the most frequent injuries suffered by the driver of the vehicle occurs in the knee joint. Thus, the present paper aims at investigating the knee to dashboard contact during a frontal collision. Admittedly, the first stage of our investigation underpinned the design of a model to encompass the dummy and the main interior elements of the vehicle. Subsequently, the main types of contacts provided by the LS-DYNA software have been analysed. In order to establish the optimal modelling variant of the impact between the knee and the dashboard various simulations have been carried out while applying different methods to define the contact. The results obtained following the simulations have been then compared to the results provided by the specialized literature.

Keywords**—** dummy kinematics, frontal collision, knee impact, LS-Dyna modelling.

I. INTRODUCTION

ONE of the most common injuries among drivers following a frontal collision occurs in the lower limbs-area. The degree of injuries' severity is influenced both by the speed of impact, as well as by the shape and materials featured by the components inside the vehicle. Consequently, the injuries suffered may imply from several days of medical care, up to the victim's infirmity.

The main cause leading to the contact between the knee and the dashboard is triggered by the slip-effect beneath the seatbelt. This effect, labelled as the "submarining" effect, occurs when the deceleration increases in a very short time.

A scientific concern upon the drivers' kinematic study has been approached in [1], for as the main objective set was to evaluate the occupant's posture change during the pre-impact braking and to explain the effects of a motorized seatbelt (MSB) on the occupant's restraint. The above mentioned study focused on low-speed sled tests on young adult male volunteers with a vehicle seat, a seatbelt and a foot rest.

The injury codes recommended by the Abbreviated Injury Scale (AIS, 1990) have been applied in [2] and [3] in order to link the injury information with the Functional Capacity Index (FCI) and the economic cost of each type of injury. In the same climate, the research study presented in [4] focuses on the optimization of the dummy and the seat position, aiming at establishing the optimum position of the dummy and the seat to meet the prescribed regulations endorsed by Euro-NCAP.

Further considerable attention has been paid, within the specialized literature, to estimate the injury degree in lower limb lesions of the driver.

Another landmark reference in current literature underpins a research study in determining the level of the knee injury, as presented in [5]. This paper presents a detailed analysis of the responses of the Hybrid III dummy, equipped with two types of legs: Denton legs on the dummy in one test and the Thor-Lx/HIIIr legs on the dummy in the other test. The predicted injury outcome from each of the leg types is compared to lower extremity trauma in real world crashes.

Fig. 1. Thor-Lx/HIIIr leg and Denton leg [5]

In [6], Rupp et al. carry out a scientific investigation on the tolerance of the human hip at fracture in frontal collisions. The tests were performed on KTH complexes of human cadavers. In this respect, a dynamic load was applied to the knee along the axis of the femur at loading rates that are representative to knee-to-knee bolster impacts in frontal collisions.

In the same line of approach, another study conducted also by Rupp et al. [7], aims at defining the ranges within which test parameters, such as occupant posture, position, and vehicle interior geometry, may vary. Based on the results obtained, the ranges of knee angles and the orientation of the knee bolster relative to the long axis of the femur during bolster loading in frontal crashes could have been estimated.

Extensive research within this field has been oriented towards virtual modelling / computer-assisted simulation of the impact knee / the dashboard. Hence, the research investigation carried out in [8], [9] and [10] reveal a detailed review of an existing LS DYNA finite element (FE) model of the Knee-Thigh-Hip (KTH) of a 50th percentile male. Admittedly, the study presented in [8] set out to establish to obtain a more appropriate and bio-fidelic tool for injury mechanisms on human lower extremities in frontal automotive collision. Thus, the material properties of the human bones – the pelvic, the femur and the patella were considered in establishing this model.

In the same spirit, the main research objective postulated in [10] focused on the validation of an existing finite element LS-DYNA human knee joint model to replicate the complex failure mechanisms when the joint is subjected to tibial axial compression loads.

II. Contact Types In LS-Dyna

In the LS-DYNA software package, the contacts that can be defined by the user fall into two main categories, namely: one-way and two-way treatment of contact.

1) One-way treatment of contact [11]

The first type of contact, i.e. the one-way treatment of contact, allows the transfer of the compression loads between the slave nodes and the master segments.

Also, if the friction between the elements is allowed and activated, the tangential loads can be transmitted as well.

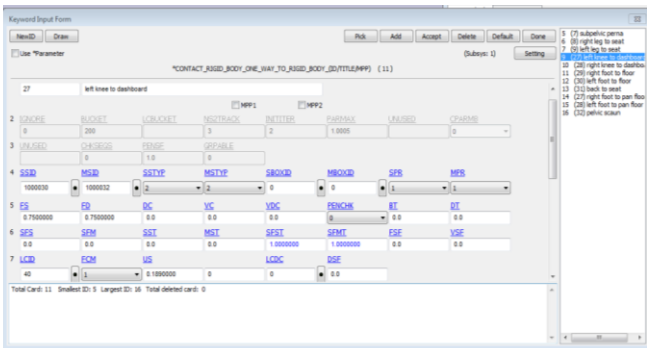

Fig. 2. Rigid body one way to rigid body – contact definition

Hence, in order to enable the transition from static condition to the dynamic one, the following condition must be accomplished: static friction coefficient to be larger than the dynamic friction coefficient.

Usually, this type of contact is used when the master is a rigid body. Thus, the *one-way* term refers to the fact that only the slave nodes defined by the user are checked for penetration.

2) Two-way treatment of contact [11]

The difference between this second category of contacts and the previously described one refers to the fact that the penetration checking can be applied in reverse as well, i.e. master slave nodes through the segments.

Two-way contacts have a symmetrical character, thus leading to identical results regardless of the selection criteria of the slave and master surface.

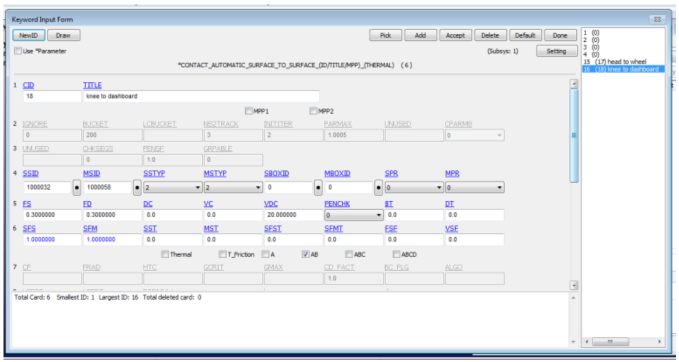

Fig. 3. Automatic surface to surface – contact definition

In most cases, when performing the analysis of a collision, it is recommended to define the CONTACT_AUTOMATIC_SURFACE_TO_SURFACE - contact type. This choice is based on the considerations of a collision analysis, i.e.: the position and the relative displacements of the elements cannot be foreseen while the deformations suffered are often considerably large.

Thus, by defining a two-way contact type both master slave nodes through segments, as in the case of one-way contacts, as well as slave master through nodes segments are being checked for penetration.

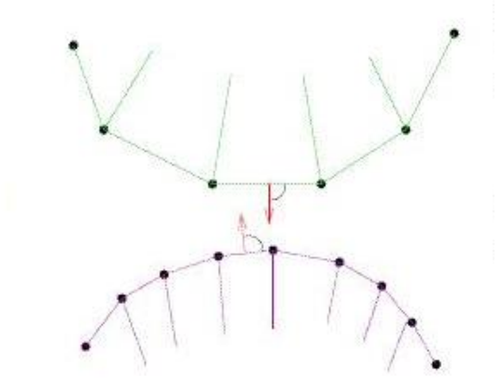

Fig. 4. Contact surface to surface [11]

III. Designing The Model

In order to analyse the influence of the frontal collision on the vehicle driver in the lower limbs region, a kinematic and dynamic model consisting of a dummy-seat-steering-wheel assembly has been designed.

Hence, aiming to obtain highly precise outcomes, in addition to the above mentioned elements, the design model also encompassed the following elements: the dashboard, the floor pedals and the steering column, as indicated in Fig. 5.

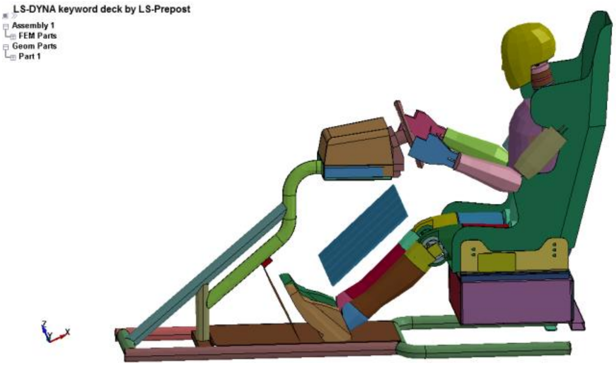

Fig. 5. Dummy – seat - steering wheel – dashboard – floor pedals assembly

A frontal collision between a medium-class vehicle and a rigid wall, with the main force direction (PDoF) oriented at 12 o'clock and an overlapping degree of 100% has been investigated for the model design.

The vehicle speed in the pre-crash phase has been fixed at 50 km/h.

Following the variation analysis of the speed diagram according to time, a time interval of 110 ms has been considered, during which the velocity varied from an initial value of 0 (mm/ms) and reached the maximum value, v_{max} = 13.686 (mm/ms) at the endpoint tf = 110 ms.

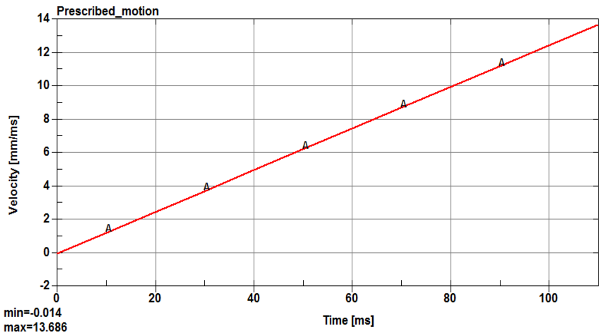

Fig. 6. Velocity variation curve for vehicle translation

IV. The Carried Out Tests

In order to establish the parameters of a comparison with regard to the type of contacts defined between the components of the dummy and various components of the vehicle's interior, several simulations have been carried out.

Three areas of interest have been established, while defining the contact type (Fig. 7):

a) Contact pelvis - seat
b) Contact left and right leg - seat
c) Contact knee - dashboard

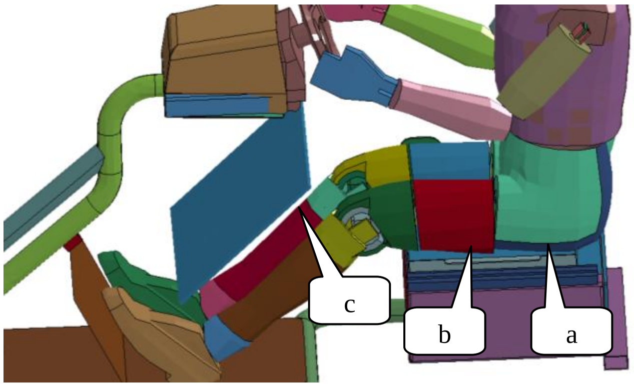

Fig. 7. Contacts defining areas

Thus, Table I indicates the conducted tests and the type of the contacts defined.

TABLE I
THE METHOD FOR CONTACTS DEFINING

Test	Pelvis – sitting chair	Foot - sitting chair	Knee – dashboard
1	RB*	RB*	RB*
2	RB*	RB*	AS**
3	AS**	RB*	RB*
4	RB*	AS**	RB*
5	AS**	AS**	AS**

*RB = Rigid body one way to rigid body
**AS = Automatic surface to surface

V. The Results Obtained

Following the undertaken simulation, special attention has been paid to the contact force between the knee and the dashboard.

TABLE II
CONTACT FORCE

Test	Contact force (N)
1	4081
2	91801
3	0
4	1315
5	9538

Consequently, the results obtained indicated that the contacts defining method in the lower limb area plays a major role upon the kinematic and the dynamic behaviour of the drivers' head region as well. Therefore, besides the contact force in the knee area, special attention was paid to the displacements and the accelerations suffered by the driver in the head area.

TABLE III

HEAD ACCELERATION

Test	Head acceleration (g)
1	450
2	538
3	670
4	634
5	416

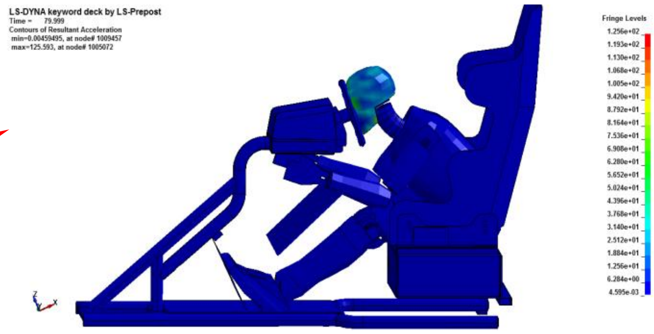

Fig. 8. Head acceleration – test 3

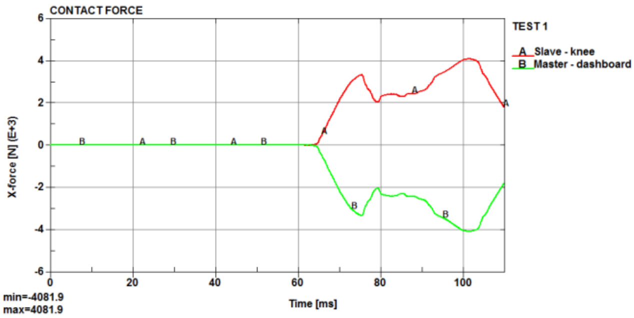

Fig. 9. Contact force – test 1

Fig. 10. Effective plastic strain – test 1

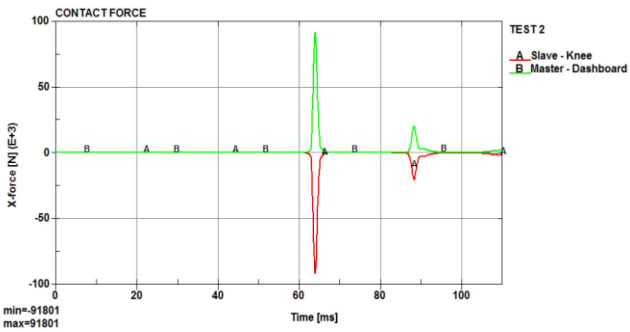

Fig. 11. Contact force – test 2

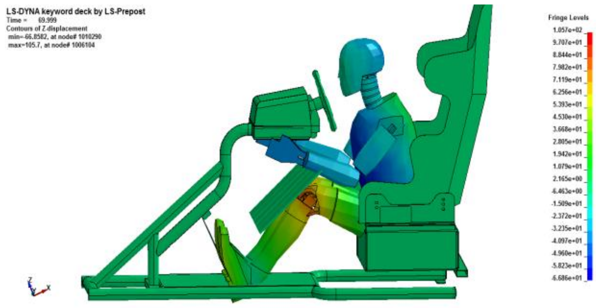

Fig. 12. Contours of Z displacement – test 2

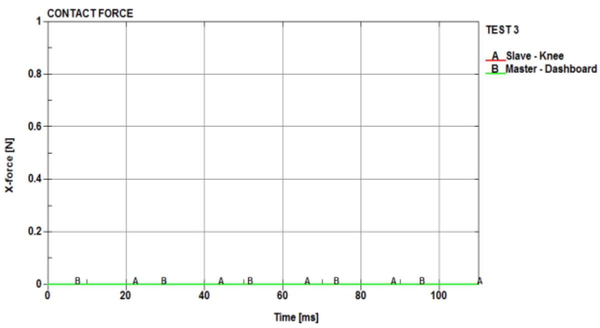

Fig. 13. Contact force – test 3

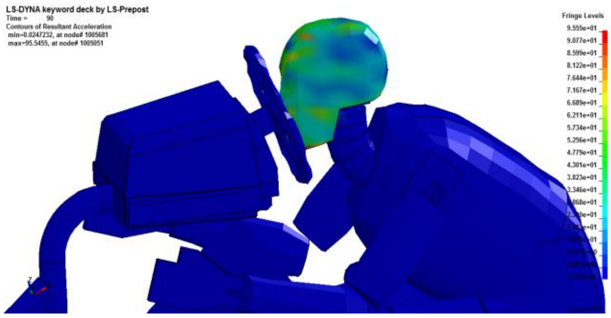

Fig. 14. Contours of resultant acceleration – test 3

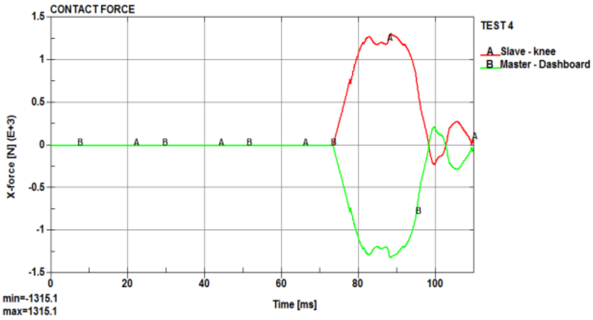

Fig. 15. Contact force – test 4

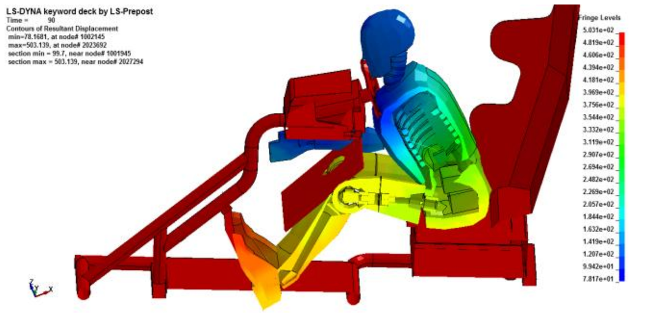

Fig. 16. Contours of resultant displacement – test 4

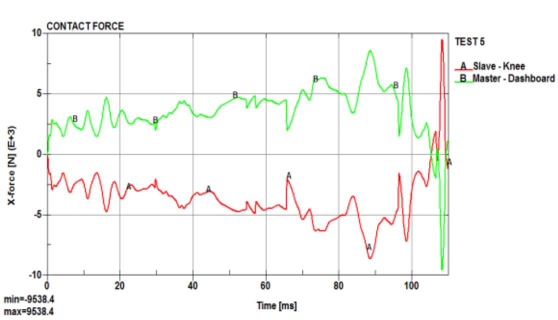

Fig. 17. Contact force – test 5

Fig. 18. Contours of resultant acceleration – test 5

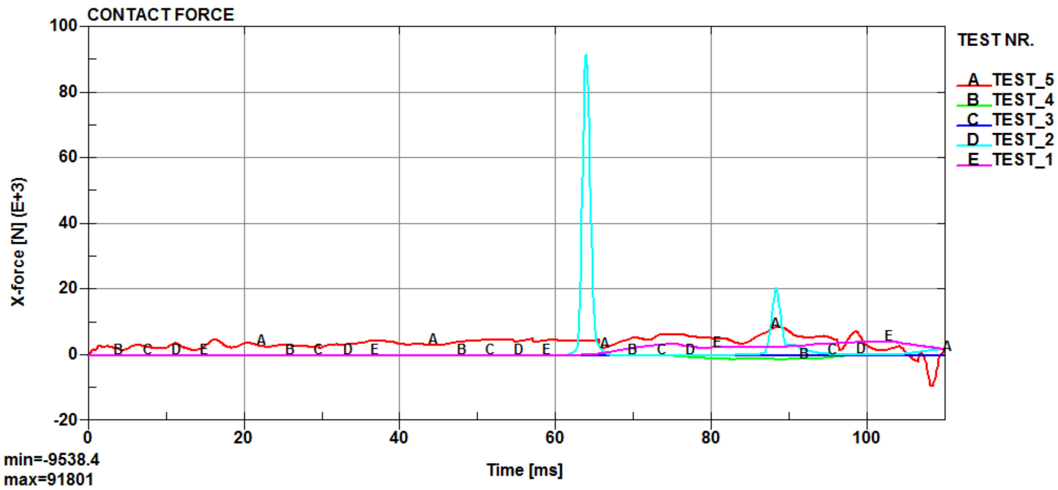

Fig. 19. Comparison of contact forces

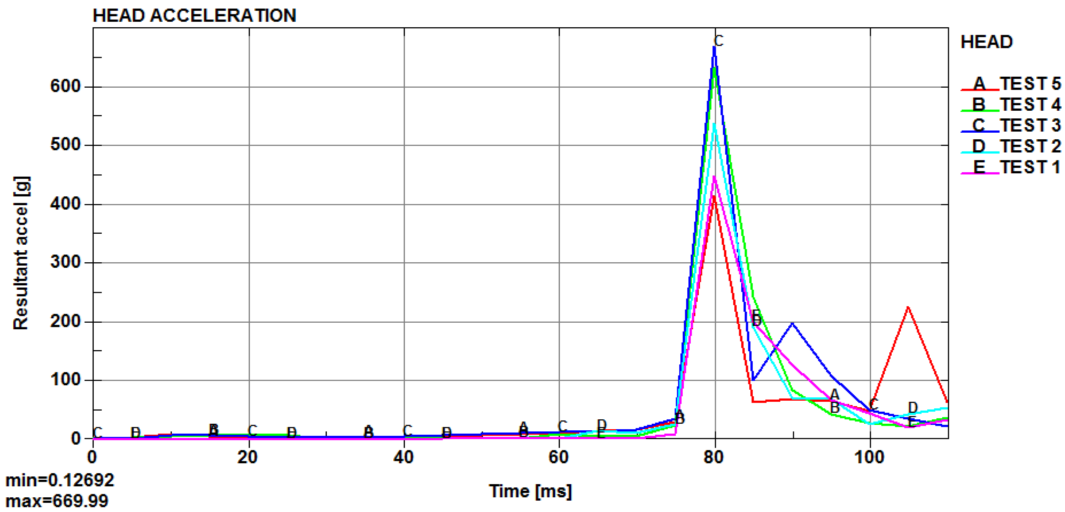

Fig. 20. Comparison of head accelerations

VI. Conclusion

By means of the simulations carried out within the above-described comparative analysis, we sought to identify the optimal contact type between the components of the dummy and the interior elements of the vehicle. In this respect, the results obtained, i.e. the kinematic behaviour of the driver and the contact defining method, are expected to be close as possible to the mechanism of a frontal collision.

Based on the results obtained the following conclusions are to be highlighted regarding the method for contact defining:

According to test 1, if all three contacts are of Rigid body one way to rigid body type, the knees of the dummy penetrate the dashboard during the contact between them, thus developing an impact force of 4081 N. In real collision situations, dashboard deformation might occur, though the knees may not penetrate the board.

The dummy's kinematics in test 2 - Automatic surface to surface – contact-types, corresponds to real-life situations. The dummy slips on the sitting chair until the impact between the knee and the dashboard. Under the circumstances, the contact force reaches the maximum value of 91801 N and the knees' displacement ends at the impact moment with the dashboard.

An Automatic surface to surface contact-type has been considered during test 3 between the pelvis of the dummy and the seat. Thus, we could notice that the impact force in this case is zero, because the knees do not enter into contact with the dash board. This type of contact prevents the diver from slipping from his seat, leading to considerably higher acceleration values in the head region.

For test 4 we have applied an Automatic surface to surface contact-type between the legs (shins) of the dummy and the seat, the other two contacts being of Rigid body one way to rigid body-type. Here, the situation presented in test 1 occurs again, as the dummy's knees penetrate the dashboard while an impact force of 1315 N develops.

All three contacts defined in test 5 have been of Automatic surface to surface – type. Thus, the dummy's pelvis displacement from his seat forwards was limited. Conversely, due to deceleration, the head of the dummy collided with steering wheel, leading to considerably higher acceleration values in the head region.

The conclusion to be drawn from the undertaken comparative analysis is that the optimal variant to define the pelvis-seat, legs-seat and knees-dashboard contact-types is the one applied in test 2, i.e.

i) Contact pelvis – seat > Rigid body one way to rigid body

ii) Contact legs – seat > Rigid body one way to rigid body

iii) Contact knees – dashboard > Automatic surface to surface.

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References

[1] Daisuke Ito, Susumu Ejima, Sou Kitajima, Ryousuke Katoh, Hisao Ito, Masataka Sakane, Tomofumi Nishino, Keita Nakayama, Tadayuki Ato, Takaaki Kimura, "Occupant kinematic behavior and effects of a motorized seatbelt on occupant restraint of human volunteers during low speed frontal impact: mini-sled tests with mass production car seat," *IRC-13-100 IRCOBI Conference 2013.*

[2] Shashi Kuppa, Osvaldo Fessahaie, "An overview of knee-thigh-hip injuries in frontal crashes in the United States," *National Highway Traffic Safety Administration, USA 416.*

[3] Shashi Kuppa, Jing Wing, Mark Haffner, Rolf Eppinger, "Lower extremity injuries and associated injury criteria," *National Highway Traffic Safety Administration, USA Paper no. 457.*

[4] Giesen Christian, Schallmo Martin, "Optimisation of occupant safety with coupling of kinematic and optimisation tools," *3rd ANSA & μETA International Conference* September 9-11, 2009 Olympic Convention Centre, Porto Carras Grand Resort Hotel, Halkidiki Greece.

[5] Shashi Kuppa, Mark Haffner, Rolf Eppinger, James Saunders, "Lower extremity response and trauma assessment using the Thor-lx/HIIIr and the denton leg in frontal offset vehicle crashes," *National Highway Traffic Safety Administration, USA Paper No. 456.*

[6] Jonathan D. Rupp, Matthew P. Reed, Chris A. Van Ee, Shashi Kuppa, Stewart C. Wang, James A. Goulet, Lawrence W. Schneider, "The tolerance of the human hip dynamic knee loading," *Stapp Car Crash Journal, Vol. 46* (November 2002), pp. 221-228.

[7] Jonathan D. Rupp, Miller, C., Matthew P. Reed, Madura, N., Ritchie, N., Lawrence W. Schneider, "Characterization of knee impacts in frontal crashes," *University of Michigan Transportation Research Institute (UMTRI)*, Department of Emergency Medicine, Department of Biomedical Engineering, Department of Industrial and Operations Engineering United States, *Paper 07-0345*.

[8] Chiara Silvestri, Mario Mongiardini, Malcolm H. Ray, "Improvements and validation of an existing LS-DYNA model of the Knee-Thigh-Hip of a 50th percentile male including muscles and ligaments, "*7th European Ls-Dyna Conference*

[9] Chiara Silvestri, "Development and validation of a knee-thigh-hip LsDyna model of a 50th percentile male," *Dissertation Submitted to the Faculty of the Worcester Polytechnic Institute*.

[10] Chiara Silvestri, Doug Heath, Malcom H. Ray, "An LS-DYNA model for the investigation of the human knee joint response to axial tibial loadings, " *11th International LS-DYNA Conference*.

[11] http://www.dynasupport.com/