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Investigation of drivers poses influence to the intervertebral forces in the junction of thoracic and lumbar spinal curves

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1. Introduction of investigation

In the 2001 year proposal for European Union traffic policy, a target to reduce number of death accidents on the road was estabished. It was confirmed by the new Europe Union traffic safety programme which was declared on 2003. The main reason for this new policy was very critical situation in car traffic safety, the number of death accidents in car crashes on 2001 year in European Union countries was 50.000 and a target for the new traffic safety programme was to reduce this number to 25.000 [1].

The car crashes are investigated with main aim to find the critical values of the forces which affects on human body and the level of human bodys tolerance. The earlier researches shows that a wedge fracture in a 52 year old cadaver seated in a rigid seat occurs at T9 vertebra with imulse acceleration at 7.5g's. Other fractures occurred at T8-T10 vertebras at levels of 13, 21 and 28 m/s^2 [2].

Also there is stated that the type of support is critical with this type of load. With lap belt only German and British pilot ejection studies show that if the spine is not kept in proper alignment wedge fractures have occurred with as little as 3 to 4 g's. The minimum support required to avoid this is lap and shoulder belts. Use of armrest will increase the tolerance further by reducing load on lumbar vertebrae. Providing support for the head and neck will reduce the severe neck flexion than can occur in sudden vertical loading [3].

Today many of the car crashes are examined in virtual reality with help of special programs. This helps to reduce costs of car crashes researches, in which human body injuries are analyzed and allows to do these researches more faster. These researches always have been complicated because the human body is very complex biomechanical construction, with nonlinear charakteristics, which may vary according different impact direction and aplied load value and speed. It is very complicated to research human body on critical situations, but this must be done in order to test existing vehicles passive safety system elements or to create new ones [4]. In earlier time some investigations were done with animals, dead bodies or even alive human. In later times and our days the situation is different, the moddeling with the purpose to research a car crash impact on drivers or passenger body is done with real vehicle and human dummy. This is faithfulness but still is sophisticated and very expencive, because only of inteligent dummys the price is above 25000£ and even more. That is why the use of computer aided modeling is optimal way in car crash test researches. In these researches there is no need of real body or vehicle, and it is possible to determine crash impact speed, applied forces changes versus time, soft tissues deformation speed and value. And according these data vehicles designers can modify existing or create new passive or active safety systems for modern vehicles which must fulfill Euro Commission reguliatons for test and acceptability criterias.

This paper represents a research of vehicle occupant postures influence to intervertebral forces during vertical impact of vehicle.

2. Object and conditions of investigation

The crash researches shows that the contact shock impulse between human body and stiff elements of the environments is the main reason of injuries in everyday life or professional sport activity. The relative speed or aplied energy are essential factors of shock impulse. The changes of theses factors have strong influence on contact force and local or common deformation value of human body versus time. According mechanical and functional resistance of human body, which mostly depend on bones texture, and external shock impulse the main characteristics are speed of the impulse and aplied energy [5]. And the main purpose of safety items, used in industry or vechicles are to minimize the values of contact forces and human body deformation. The example of these safety devices are vehicle safety belts, which are used with the purpose to reduce the human bodys free movement during impact. Of course the use of these safety devices must be considered with understanding that if they restrict too much free movement of the body more than it is necessary, the sense of driving comfort could be lost.

Humans bones texture and features are unique. The bones structure (Fig. 1) can ensure proper security and stiffness for the whole human body. Bones texture consist of cells and matrix, it has a lot of nonorganic elements which is in close coreliation with organic matrix [6]. Bones mineral elements are set between fibres of the collagen. These fibres are elastic, flexible and resistant to extension.

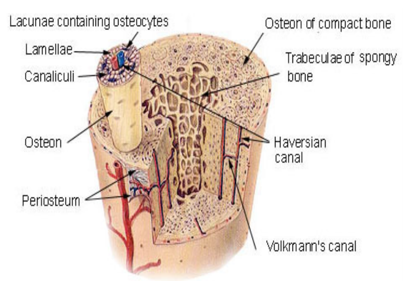

Fig. 1 Bones structure

Structural piece of a bone is osteon, with canal for nerves which is placed in central zone. The osteon consist from concentrical layer of plates, along every layer small holes are displaced, with one cell of osteocit inside [7].

The cells proceses from every osteocit reaches canals and veins- in this way bone cells are feeded by human blood. Fibres of callogen and canalls join all plates in the matrix.

This tangle of collogen fibres inside osteon ensures mechanical resistance of bone. The plates between osteons are from the same material and are coincident with them [8]. In macroscopic level bone consist from two types of material compact and porous. Compact material compose bones outer layer and it's structure is very thick almost like of tooths. Porous material consist from thin plates which creates porous structure, in gaps between the plates red bones marrow are placed. Compact material always rim about porous, the proportion between these layers depends on function of the bone. The main mechanical charakteristics of the bone are hardiness and stiffiness. Usually they depend on where the bone is placed. The aplied external load causes deformation and structural changes in the bone, this characteristic is comon for all nature [9]. In real life bones could be affected by tension, compression, bend, cutting, twisting. Hardiness of the bone depends on external load direction. The muscles contraction can lower or even eliminate load value on the bone. As was mentioned above, the impulses relative speed has great effect on damages value. The bones have plastic and elastic charakteristic and it is observed that its behaviour depend on enclosed load speed. A bone becomes stiffer and can withstand bigger load if applied speed is greater [6]. The bone can break when external load reaches its critical value, or from fatique when there are several smaller repeating external loads and the muscle can not neutralize destructive effect of these loads.

3. Computational model

For research a computational model consisting of human body and vechicles interior environment was created. The kinematical-dynamic analysis software MSC.ADAMS 2003 environment tools were used for the vehicle's interior elements: floor, seat pad and back and the safety belt creation. MSC.ADAMS plug-in BRG.LifeMOD was used with the purpose to create driver dummy consisting of 19 segments, with natural drivers posture. The dummy's body segments are created from "Peoplesize" antrophometric database, generating segments dimensions, mass and inertia tensors. The created model allowed to examine various types of dummy: skeletal, skin, clothed, ellipsoid or stick figure.

Kinematic constraints- dummy joints which connect two adjoining body's segments were established as passive type joints, complete set for the whole body. At the same time torque functions are established for degree of freedom of the joint. The torque function is created from the Hybrid III database of torque functions. It is based on a nonlinear joint stiffness, damping, friction and hysteresis losses, specific to each DOF for each joint as derived from the physical Hybrid III crash dummy.

The soft tissues: ligaments and muscle-tendons in the model are created as the passive type. After the segments were created and the joints were insteled on the dummy, the dummy was placed in drivers position for analysis. The primarilly angles for each joint were set from postures database. During the investigation dummys posture was modified several times.

Contact forces between the body segments and the environment objects are created using ellipsoid plate contact elements algorithm. The segment ellipsoids created with the base model are used to create the contact force between each segment and the objects of the environment which include vehicle interior: seats, seat pad, steering wheel, safety belt, floor, pedals. The ellipsoid-plate contact elements represent a fast method of generating contact interactions. The impact force produces normal force and transverse friction forces based on input parameters.

The general form of the contact force function [10] is

$$F_n = k\left(ge\right) + Step\left(g, 0, 0, d_{max}, c_{max}\right)\frac{dg}{dt}$$

where g represents the penetration the ellipsoid into the plate; dg/dt is the penetration velocity at the contact point; e is positive real value denoting the force exponent; d_{max} is positive real value specifying the boundary penetration to apply the maximum damping coefficient c_{max}.

External load is applied by defining kinematic excitation described as a pulse of vertical upward acceleration equal 9.8 m/s^2 of the seat and the floor with the impact duration - 1s. To evaluate maximal values of intervertebral forces in the junctions of four main spinal curves four additional contact elements NScon2, NScon3 and NScon4 have been created in between the end vertebrae of these curves [11]. Stiffness and damping characteristics of these contact elements are set the same as the human vertebras (stiffness – 1740 kN/m, damping – 17400 Ns/m) [10]. An exception is with the element NScon1, it is placed between vehicles seat and the dummy. Changes in its stiffness and damping values have an effect on models seats pads characteristics.

Formerly performed research has established relation between impact load and stiffness or damping values and intervertebral forces in the junction of thoracic and lumbar spinal curves. But there the relation between intervertebral forces in the junction of thoracic and lumbar spinal curves and drivers posture was not established.

In this research contact element NScons1 was set with the stiffness 2436 kN/m and damping 52200 Ns/m. Angular value as initial for hip was set 90 degree and for drivers knee 50 degree.

In the first stage of the research the hip angles influence on intervertebral forces in the junction of thoracic and lumbar spinal curves was found. Hips angular settings was changed several times (30, 50, 70, 80, 90, 110 degrees), and changes of contact inervertebral forces in the junctions were observed, as the other initial conditions like external load, seats damping and stiffness characteristic, impact duration, posture remained unchanged. In the second research stage all above mentioned conditions impacts duration, acceleration, vechicle seat characteristics were constant, with dummys hip setting - 70 degree, but dummys knee setting was changed several times: 50, 45, 40, 60 degree.

In order to find out which posture of the driver can guarantee the lowest contact force between vertebraes in the junction of spinal curves, and to establish safe vehicle seat angular setting, also to determine the relationship between seat angular settings or drivers posture and intervertebral contact forces, the following cases were examined:

- estimation of intervertebral force in contact element NScon3. With different angular settings for dummy hip (six positions: from 30 to 110 degree);
- estimation of intervertebral force in contact element NScon3. With different angular settings for dummy knee (four positions: from 40 to 60 degree).

4. Results and discussion

In this simulation vertical acceleration of the vehicle interior is transmitted to the dummy through vehicle's seat pad, which stiffness and damping correspond analogical parameters of the contact element NScon1. After that impact pulse is transmitted along dummy bodys segments: soft tissues, bones, vertebrae segments, starting from the lowest segments (pelvic, lumbar) where its value decreases, because it is partially absorbed by human body's soft tissues and humans backbones structure, and then it reaches upper backbones segments (thoracic and cervical).

The obtained results show that the highest contact force values with the force acting in upward direction (tension or compression) are in the contact element NScon3 which is placed between thoracic and lumbar spinal curves [11]. And according data retrieved from NScon3 it could be stated that the junction between two spinal curves: thoracic and lumbar are the place where the biggest part of applied energy are absorbed by human body structure.

The maximum reached value in NScon3 for contact force is 164 N, when the driver dummy posture is with hip setting 110 degree. This value was reached in 0.05 s. After that the character of force curve has some small fluctuations and the second maximal value of 115 N is reached after 0.4 s (Fig. 2).

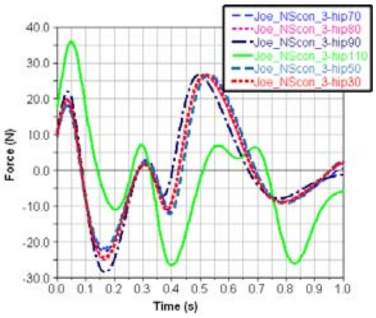

Fig. 2 Dependence of intervertebral force on dummy hip angular setting

In all other cases with different drivers posture hip settings (30, 50, 70, 80, 90°) with applied external load of the same value settings, and other conditions unchanged, contact force and its characteristics are similar to each other, the maximal values are significamtly smaller: 89 N are reached in 0.05 s from the impact, second contact forces maximum - 112 N is reached after 0.17 s from the impact beginning. And the top value 116 N force is reached in 0.5 s. The differences between these curves is small and it could be stated that they are off the point.

In the second research stage, the main purpose of which was to find the influence of drivers knee angular posture on intervertebral contact forces in the junction of thoracic and lumbar spinal curves with acting external vertical upward direction impact.

All settings for external load: acceleration - 9.8 m/s^2, impact duration - 1s, dummys posture and contacts were set as constant except dummys knee angular setting.

It was changed several times from 40, 45, 50 to 60 degree. After the researched system was affected with external load, the contact force change between manikins backbones vertebras contact element in dependence of manikins knee position was stated. The biggest part of applied energy was absorbed in the junction of thoracis and lumbar contact element NScon3. In others contact elements the dependence of intervertebral forces has almost linear character, meanwhile in NScon 3 it has wavy form (Fig. 3).

In contact element NScon3 after 0.05 s from the simulation beginning intervertebral contact force reaches its first maximum value 89 N, after 0.15 s it reaches it's second maximum - 111 N, then there are small oscilliation and after 0.5 s it reaches his the top value of 120 N.

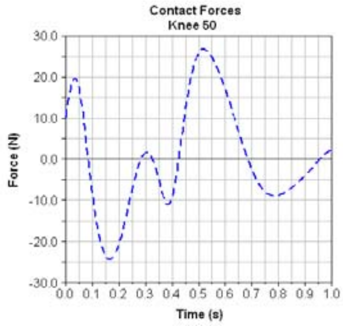

Fig. 3 Dependence of intervertebral force on manikin knee angular setting

5. Conclusion

A simulation was performed using the softwares "MSC. Adams" environment additive "BRG. Lifemodeler" tools with the purpose to find the influence of vechicle drivers bodys position on intervertebral contact force values with acting external kinematical impact vertical upward direction.

The computational model consisiting of vechicles floor, seat, safety belt and the dummys body, consisting of 19 segments with the joints and soft tissues, posed in drivers posture was created. In he first stage of this simuliations the dummys hip angular values were changed several times and changes in intervertebral forces in the junction of thoracic and lumbar spinal curves contact force values were observed:

- the top values of intervertebral contact forces were reached in contact element NScon3 in the junction place of thoracis and lumbar spinal curves;
- the maximal contact force value is 164 N. This value is reached after 0.05 s from the impacts start in contact element NScon3 with drivers dummys hip angular setting of 110 degree. With all other hip angular settings the reached value of the intervertebral contact force after the same time is 89 N.

In the second research stage there was stated that intervertebral contact forces values do not depend on drivers knee angular setting: With all knees angular settings, the intervertebral contact forces did not change in value and charcteristics. The maximal reached value was 120 N. The best result with minimal intervertebral contact forces in the junction of thoracis and lumbar was obtained when dummy was posed with hip angular setting of 70°.

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KRŪTINĖS IR LIEMENS STUBURO LINKIUOSE VEIKIANČIŲ TARPSLANKSTELINIŲ JĖGŲ PRIKLAUSOMYBĖS NUO VAIRUOTOJO SĖDĖSENOS TYRIMAS

R e z i u m ė

Atliktas modeliavimas kurio metu nustatyta vairuotojo sėdėsenos įtaka tarpslankstelinėms jėgoms, veikiančioms tarp stuburo linkių, veikiant vertikalai smūginei apkrovai. Sukurtas tiriamasis modelis, kuriame tarp manekeno stuburo linkių sandūrų sukurti kontaktiniai elementai kurie seka tarpslankstelinių jėgų pokyčius, Tyrimo eigoje buvo keičiama vairuotojo sėdėsena, keičiant kelių ir dubens sanarių padėtis. Buvo rasta vairuotojo sėdėsenos poza kuriai esant tarpslankstelinės kontaktinės jėgos veikiančios tarp stuburo linkių yra minimalios.

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INVESTIGATION OF DRIVERS POSES INFLUENCE TO INTERVERTEBRAL FORCES IN THE JUNCTION OF THORACIC AND LUMBAR SPINAL CURVES

S u m m a r y

The investigation was performed with purpose to establish correlation between drivers pose and intervertebral forces in junction of thoracic and lumbar spinal curves with vertical direction kinematical upward impact. An model created for analyzis, it consist of manikin and envinronment. Between manikins vertebras are placed contact elements which monitor intervertebral force changes. During simuliation there was changed manikins hip and knee settings and monitored changes of intervertebral forces. According stated rezults of this investigation, there was established driver pose with lowest intervertebral force values.

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ИССЛЕДОВАНИЯ ВЛИЯНИЯ ПОЗЫ ВОДИТЕЛЯ НА МЕЖПОЗВОНОЧНЫЕ СИЛЫ В СТЫКЕ ГРУДНОГО И ПОЯСНИЧНОГО ИЗГИБОВ ПОЗВОНОЧНИКА

Р е з ю м е

Исследовано влияние позы водителя на межпозвоночные силы в стыке грудного и поясничного изгибов позвоночника при ударном воздействии. Создан манекен, сидячий в позе водителя, с окружающей средой. Между изгибами позвоночника были установлены контактные элементы с помощью которых было исследовано изменения межпозвоночной контактной силы под ударным воздействием вертикального направления. В ходе исследований изменялось положение манекена водителя, угол наклона колен и бедра, при этом наблюдалась изменения межпозвоночной контактной силы. По полученным данным установлена поза водителя, при которой межпозвоночная контактная сила мимальная.

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