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The influence of seat pad stiffness and damping on the intervertebral forces in the junction of thoracic and lumbar spinal curves

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1. Introduction

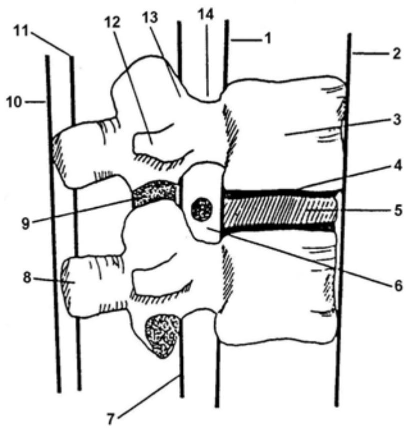
Human spine is a complex structure, the which main function of which is to protect spinal cord and to transfer loads from head through trunk till pelvis. Spine consist of 24 stiff vertebrae, connected by intervertebral discs, allowing slight movement of the vertebrae due to elastic deformation of the discs, thus giving a flexibility to the whole spine. The pressure acting the intervertebral joint disc is about 10 N/cm^2 under the normal conditions [1-10], and can be increased substantially for longer period of time, for example, due to loading by carried tote, or exceeded rapidly but for short due to car accident [6]. Both these cases lead to the unacceptable consequences, but the impact has usually more serious effect to the state of health [7], especially – when acting along the spine. Thus namely this case of external loading of human spine is under investigation in this paper, being the consequent research of initiatory research, presented in [7].

2. The anatomical model of spinal intervertebral joint

In human anatomy, the vertebral column (backbone or spine) is a column of 24 vertebrae, the sacrum, intervertebral discs, and the coccyx situated in the dorsal aspect of the torso, separated by spinal discs. It houses the spinal cord in its spinal canal [9].

Viewed laterally the vertebral column presents several curves, which correspond to the different regions of the column, and are called cervical, thoracic, lumbar, and pelvic. The cervical curve, convex forward, begins at the apex of the odontoid (tooth-like) process, and ends at the middle of the second thoracic vertebra; it is the least marked of all the curves. The thoracic curve, concave forward, begins at the middle of the second and ends at the middle of the twelfth thoracic vertebra. The lumbar curve begins at the middle of the last thoracic vertebra, and ends at the sacrovertebral angle [12]. It is convex anteriorly, the convexity of the lower three vertebrae being much greater than that of the upper two. The pelvic curve begins at the sacrovertebral articulation, and ends at the point of the coccyx; its concavity is directed downward and forward.

The main functional unit of the spine is a biokinematic pair, consisting of two vertebrae and soft tissues connecting them. The front part of the biokinematic pair consists of bodies *3* of two vertebrae, intervertebral disk *5* and front longitudinal ligament *2*, and the back part of pair includes bends *13* and processes *8*, *12* of corresponding vertebrae, intervertebral joint *9* and ligaments *1*, *10* and *11* (Fig. 1) [3-4]. Vertebra‘s bend is joined by yellow ligament. Also there are cross and crest ligaments which join adjacent vertebra‘s bends.



1- back longitudinal ligament
2- front longitudinal ligament
3- vertebra body
4- gristle plate
5- intervertebra disk
6- intervertebra orifice
7- yellow ligament
8- crest process
9- intervertebra joint
10- crest ligament
11- midcrest ligament
12- transversal crest
13- bend
14- channel

Fig. 1 Intervertebra joint

Human vertebrae are combined of two parts: body and bend [17]. Vertebra‘s bend from both sides of the body begins with vertebra‘s bend stalks, which become flat and shape bend plates. There are two pairs articular processes based on the plate of bend. Every process creates vertebra‘s joints with appropriate processes from another bend. Spinal vertebra has two upper and two lower processes and consist of four vertebra joint. Vertebra joint has thin but strong capsule which has inside a layer of synovial tissue.

The biokinematic pair of two adjacent intervertebrae connected by the disk has a feature, when one of joints is broken (faulty) other two joints have instability and there is a possibility of degenerative changes of the structure [3-13]. There are two ways of classifying backbone injuries [11]: B.L. Allen and R.L. Ferguson has offered a mechanical system and F. Magerl has offered a system which refers to pathologomorphologycal aspect [5-6]. According to the mechanical system, backbone injuries are classified according to the position of particular body segments. Injury classification according F. Magerl refers to injuries of patomorphology of vertebrae.

Intervertebra disk has a nucleus, which normally works under hydrostatic condition, when pressure is distributed gradually over the disc surface. Pressure inside the intervertebra joint is about 1.5 times higher in comparison with external load [1]. Bulk of nucleus can‘t change in size under additional load, so in such case the matter of bulk is pushed outside the intervertebra joint fibroma ring. This effect is more significant when the surfaces of vertebra are not parallel. The critical load can lead to the fail of fibroma ring and occurring vertebra hernia.

Again, when the spine is subjected by additional external load, human spine has a greater resistance to pressure loads because of its shape, which is a combination of curves [14]. Because of these curves the spine has better damping and shock absorbing characteristic, herewith having proper rigidity and stability [2].

3. Computational model and the scheme of research

Computational model, consisting of the human body dummy in driver's posture and elements of vehicle interior, having direct contact with the sitting dummy, was created in kinematic-dynamic analysis software MSC.ADAMS 2003 environment by using software BRG.LifeMOD [8]. Vehicle's interior includes the floor, seat pad and back and the safety belt, created by means of MSC.ADAMS tools. The MSC.ADAMS plug-in BRG.LifeMOD was used for modeling driver's body (the 50th percentile human body model from „Peoplesize" (UK) database). The driver was "seated" on the seat by ensuring it's proper posture and defining contact with seat pad, back and safety belt and appropriate segments of driver's body. Each contact pair was defined by prescribing appropriate stiffness, damping and friction.

The general form of the contact force function is

$$F\,n = k*(g**e)+Step\,(g,0,0,d\,max\,,c\,max\,)*dg/dt \quad [18]$$

External load is applied by defining kinematic excitation described as a pulse of vertical upward acceleration of the seat and the floor (impact duration is 1 second, acceleration – 9.8 m/s^2 [15]. To evaluate maximal values and to observe the variation in time of the 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 (Fig. 2). To ensure original stiffness and damping of the spine their stiffness and damping are prescribed the same as corresponding parameters of the biokinematic pair of two vertebrae, connected by intervertebral disk (stiffness – 1740 kN/m, damping – 17400 Ns/m). However stiffness and damping parameters of contact element NScon1, which is placed between seat pad and the lower torso of human's body and is used to simulate the seat pad, differs significantly from other contact elements and is changed during computations (from 243.6 to 1392 kN/m and from 52200 to 121800 Ns/m correspondingly).

In the first stage of research the computations of intervertebral force in the junction of thoracic and lumbar spinal curves was performed under the different boundary conditions, i.e. by using different values of the impact load and stiffness and damping of seat pad, having the aim to verify the results of computations performed earlier [7], that is to ensure that external force is mainly absorbed in contact pair NScon3.

In the first case the initial value of the size of impact was doubled, while other parameters of the system (stiffness, damping and contact friction) remained the same, than the computations were carried out with doubled size of impact and stiffness of contact NScon1 reduced twice. And finally doubled size impact was applied to the system with initial stiffness and friction, but doubled damping of contact element NScon1.

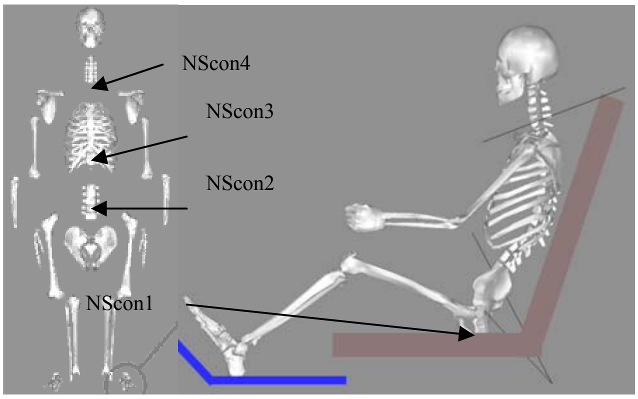


Fig. 2 Computational model with contact elements of interest

In order to find out which parameter of seat pad, stiffness or damping, has major influence on intervertebral force in the junction of thoracic and lumbar spinal curves, and to determine the relationship between seat stiffness and damping, giving the lowest contact force between vertebrae, the following cases were examined:

- computation of intervertebral force in contact pair NScon3 loaded by impact of initial size but with different values of damping (five values: from 52200 to 121800 Ns/m);
- computation of intervertebral force in contact pair NScon3 loaded by impact of initial size but with different values of stiffness (five values: from 2436 to 1392 kN/m).

4. Results and discussion

The vertical acceleration of the vehicle interior is transmitted to the body through vehicle's seat pad, which stiffness and damping correspond analogical parameters of the contact element NScon1[16]. After that the impact pulse is transmitted along dummy's vertebrae segments (curves) starting from the lowest segments (pelvic, lumbar) where it's value decreases, because it is partially absorbed by human body's soft tissues and structure of the backbone, and then it reaches upper backbones segments (thoracic and cervical).

The first stage computations showed, that in all three mentioned cases the highest values of the intervertebral forces has been obtained in contact NScon3, that is namely in the junction of thoracic and lumbar spinal curves. The maximum value of contact force – 9674 N – occurred in NScon3 when the system having initial configuration was loaded by doubled impact.

It can be seen also, that the contact force is absorbed mostly in the junction of lumbar and thoracic spinal curves (contact element NScon3). The character of curves of intervertebral forces is here almost symmetric, meanwhile in NScon1, NScon2 and NScon4 they are non symmetric. In all examined cases intervertebral force reaches it's maximum value in first quarter of impact, after that it drops and oscillates decreasingly about zero value.

The results of computations of the size of intervertebral forces in the junction of thoracic and lumbar spinal curves (contact element NScon3 in computational model) showed that the maximum contact force value under given loading reaches near 6670 N when the stiffness of the seat pad is maximal (1.4E4), and decreases about 1.43 times (up to 4670 N) when the stiffness of seat pad is reduced 3.5 times. The influence of seat damping parameters on maximal value of contact force is practically negligible – it remains practically the same while the damping is changed from 52200 to 69600 N·s/m, so the stiffness of the seat pad has major influence on the intervertebral forces in comparison with damping (in the specified ranges).

After the variational computations it was obtained, that the best result (minimal intervertebral force) is reached when the damping is 87000 N·s/m (Fig.3) and stiffness is 1044 kN/m (Fig.4). This combination of stiffness and damping values should be recommended for the vehicles seat.

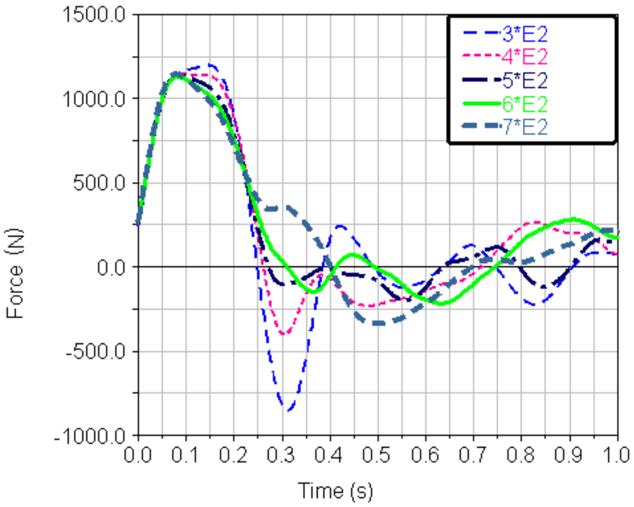


Fig. 3 Dependence of intervertebral force on seat pad damping

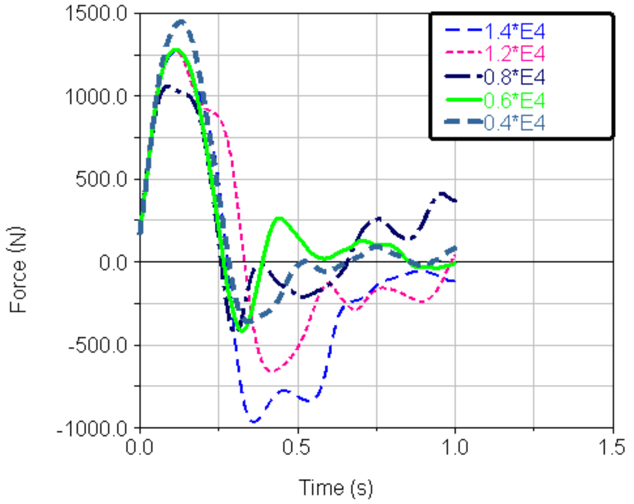


Fig. 4 Dependence of intervertebral force on seat pad stiffness

5. Conclusions

In order to find out the influence of car seat pad stiffness and damping on the size of intervertebral forces in the junction of thoracic and lumbar spinal curves a computational model has been created using kinematical-dynamical analysis software MSC.Adams and LifeMOD which includes human‘s dummy in driver's position, having the spine consisting of four curves with special contact elements between them, and the vehicle interior details, floor, safety belts, pad and the back of vehicle's seat. Between relative model elements the were established joints and contact condition.

The response of the system to the kinematical impact in vertical upward direction was estimated taking into account different parameters (stiffness and damping) of contact between the driver's body and the seat. On the basis of the results of computations the following conclusions can be withdrawn:

- the highest values of the intervertebral forces arise in the junction of thoracic and lumbar spinal curves;
- the maximum contact force value reaches near 6670 N when the stiffness of the seat pad is maximal (1,4E4), and decreases about 1,43 times (up to 4670 N) when the stiffness of seat pad is reduced 3,5 times;
- the influence of seat damping parameters on maximal value of contact force is practically negligible;
- minimal intervertebral force under given loading is obtained when the damping is 87000 N·s/m and stiffness is 1044 kN/m.

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SĖDYNĖS STANDUMO IR SLOPINIMO PARAMETRŲ ĮTAKA TARPSLANKSTELINĖMS JĖGOMS KRŪTINĖS IR LIEMENS STUBURO LINKIŲ SANDŪROJE

R e z i u m ė

Tyrimo tikslas – nustatyti sėdynės standumo ir slopinimo parametrų įtaką tarpslankstelinėms jėgoms krūtinės ir liemens stuburo linkių sandūroje veikiant smūginei apkrovai. Tuo tikslu kinematinės-dinaminės analizės sistema MSC.Adams bei jos priedu biomechaninių sistemų dinamikai tirti LifeMOD sukurtas erdvinis skaičiuojamasis modelis, apimantis patį vairuotojo manekeną, kurio kūno padėtis atitinka vairuotojo sėdėseną ir keičiamo standumo bei slopinimo sėdynę. Sukurtame vairuotojo modelyje stuburas sudarytas iš keturių segmentų, atitinkančių žmogaus stuburo linkius. Tyrimų metu apskaičiuotas kontaktinės jėgos tarp stuburo slankstelių kitimas krūtinės ir liemens stuburo linkių sandūroje sistemą žadinant kinematiniu impulsu vertikalia kryptimi esant skirtingiems žmogaus-sėdynės kontakto parametrams (standumui bei slopinimui). Nustatytas automobilio sėdynės standumo ir slopinimo santykis, kuriam esant kontaktinė jėga tarp stuburo slankstelių yra mažiausia.

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THE INFLUENCE OF SEAT PAD STIFFNESS AND DAMPING ON THE INTERVERTEBRAL FORCES IN THE JUNCTION OF THORACIS AND LUMBAR SPINAL CURVES

S u m m a r y

This paper presents the investigation having the purpose to find correlation between intervertebral forces in the junction of thoracic and spinal curves and car seat stiffness and damping under the impact loading. The 3D computational model of system to be analyzed was built by means of kinematical-dynamical analysis software MSC. Adams and LifeMOD. The computational model includes human‘s dummy in driver's position, body with a spine consisting of the four segments, corresponding the curves of the human spine, and seat with parametrically defined stiffness and damping. A variation of the contact force between spinal vertebrae in the junction of thoracic and lumbar spinal curves under kinematical impact in vertical upward direction was estimated under the different parameters of contact between the driver's body and the seat (stiffness and damping). Relationship between seat stiffness and damping was established giving the lowest contact force between vertebrae.

Е. Рукуйжа, В. Эйдукинас, И. Дулявичюс

ВЛИЯНИЕ ЖЕСТКОСТИ И ДЕМПФИРОВАНИЯ СИДЕНИЯ НА МЕЖПОЗВОНОЧНЫЕ СИЛЫ В СТЫКЕ ГРУДНОГО И ПОЯСНИЧНОГО ИЗГИБОВ ПОЗВОНОЧНИКА

Р е з ю м е

Целью данной работы являлось исследование влияния жесткости и демпфирования сидения на межпозвоночные силы в стыках грудного и поясничного изгибов позвоночника под ударным воздействием. Трехмерная модель исследуемой системы построена с использованием системы кинематического-динамического анализа MSC.Adams и LifeMOD. Модель включает тело водителя, позвонок которого состоит из четырех сегментов, соответствующих дуги позвонка человека, и сиденье с параметрической жесткостью и демпфированием. В ходе расчетов получены кривые изменения межпозвоночной контактной силы в стыке грудного и поясничного изгибов позвоночника при ударном воздействии вертикальным кинематическим импульсом при различных значениях жесткости и демпфирования сидения. Установлено соотношение между жесткостью и демпфированием сидения, при котором межпозвоночная контактная сила достигает наименьшего значения.

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