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How do Different Load Cases Affect the Spinal Structures of a Well-balanced Lumbar Spine? A Multibody Simulation Analysis

Sabine Bauer, Dietrich Paulus, Eva Keller

Abstract — **In this research, a multibody simulation model of the lumbar spine is created that implements the biomechanical properties of the intervertebral discs, the ligamentous structures and the facet joints. The main objective of this study is to design a "well-balanced" lumbar spine model. Therefore the vertebrae are so oriented that the characteristic criteria of a well-balanced lumbar spine are taken into account. Before the effects of different load cases on the spinal structures of the well-balanced lumbar spine model are analyzed, the validation process is clarified and discussed in detail. Starting the simulation with the natural load case, the upright state with F_{ex} = 500N, the external load F_{ex} is incremental increased of 100N up to an external load of F_{ex} = 1000N.**

The results show that with the increase of the external load, the intervertebral disc forces within a FSU increasing as well. But comparing the disc force between the individual FSUs, in the transition region of the lower lumbar lordosis to the upper lumbar lordosis, the intervertebral disc force of all FSUs L2-L3 decreases under the different load cases. With regard to the interspinal rotations it should be noted that the chances of the rotation angles are very small, which is suspected in the case of a well-balanced spine. The biomechanical behavior of the facets is almost similar to that of the intervertebral discs. An exception is the biomechanical behavior of the facet joints of the FSU L1-L2. The facet load of FSU L1-L2 drops to an extremely small value. This can be explained by the orientation of facet surfaces.

In summary it can be stated that the presented results have been expected to a certain extent before, but also new findings regarding the effects of the spinal alignment to the spinal structures were obtained.

Index Terms— **well-balanced lumbar spine, multibody simulation, different load cases, intervertebral disc, facet joints.**

I. INTRODUCTION

Back pain is the most common type of pain in men and women of all ages. Considering the frequency of health complaints about back pain, it turns out that 70 to 85% of the population is affected during their lifetime of back pain [1]. Causes of back pain are primarily degenerative changes of the skeletal system and the intervertebral discs, including the resulting consequences such as instabilities or dysesthesias with narrowing of the spinal canal and compression of the associated nerve roots. Before biomechanical complex relationships in variations of the spinal alignment can be studied, the basic knowledge of the biomechanical behavior of a well-balanced spine is unavoidable.

A variety of studies deal with the simulation of biomechanical properties and the load situations of the lumbar spine: With the help of the FiniteElement- (FE) models of Rohlmann [2], [3], [4] and Zander [5] the effects of various load cases on the interspinous structures of the lumbar spine are analyzed. In further research FE models of single lumbar segments are created, to determine the specific load conditions inside the intervertebral discs [6], [7], [8] [9], [10]. The simulation of degenerative effects is the focus of the biomechanical analysis of Galbusera [11] and Rohlmann [12]. In these studies, however, no precise statements about the sagittal balance of modeled spine are taken. The aim of this project is therefore to determine the stress distribution of the spinal structures of the lumbar spine with consideration of the sagittal balance by a 3D Multibody Simulation- (MBS-) model (Fig. 1). Therefore various load cases and their effects on the spinal structures are analyzed.

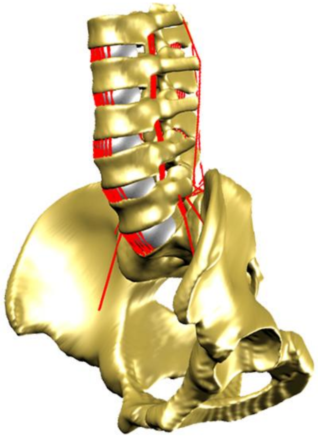

Fig. 1 MBS-model of a well-balanced lumbar spine

II. METHOD

A. Surface generation and alignment of the lumbar spine model

The body surface model is obtained by segmentation of images of a computed tomography (CT). The templates of the body surfaces are artificial vertebrae, which represent the average size of an European. For segmentation and

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visualization of the DICOM data, a plug-in is developed [13], [14] to allow an individual processing of the CT data.

The vertebral bodies are oriented so that the spinal alignment corresponds a well-balanced spine. According to Roussouley [15] the spine is well-balanced if the sacral slope is between 35° und 45°, the apex of the lumbar lordosis is in the center of the L4 vertebral body, the lower lordosis becomes more prominent and the inflexion point is located at the thoracolumbar junction. Furthermore an average of four vertebral bodies constitutes the arc of lordosis and the average global lordosis angle is 61°. All these conditions are fulfilled in this model. But it should be noted that the proportions in Fig. 2 should be understood as an approximation to the real model dimensions. It can therefore occur deviations from the model.

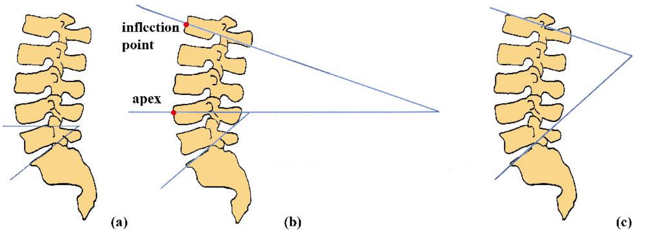

Fig. 2 Alignment of the lumbar spine model

The sacral slope, the angle between superior endplate of S1 and the horizontal axis, is 38° (Fig. 2(a)). The lower arc of lordosis is with 41° more prominent than the upper arc of lordosis with 20° (Fig. 2(b)). The apex of lumbar lordosis is nearly in the center of L4 and the inflection point is located where the lordosis curve turns in kyphosis (Fig. 2(b)). The lordosis tilt angle in this model, angle between the anterior superior edge of S1and the inflection point, is calculated and is nearly zero. Also an average of four vertebral bodies constitutes the arc of lordosis. The average global lordosis angle is 61°.

B. Biomechanical properties of the spinal structures

The intervertebral disc connects two adjacent vertebral bodies and is realized as an elastic element. It is defined by six degrees of freedom and a distinction is made between the three components of force F_x, F_y and F_z and three components of torque M_α, M_β, and M_γ. The mechanical behavior of disc force, deformation and deformation velocity is described by the relation

$$F = c \cdot CSA \cdot \Delta r + d \cdot \Delta r' \qquad (1)$$

with the parameter for stiffness c, the cross section area (CSA) and the deformation Δr. Furthermore the parameter for damping d and deformation velocity Δr' are taken into account. The stiffness c and damping d parameters for axial compression and shear behavior are taken from literature [16]. The biomechanical behavior of the intersegmental rotation of the discs is realized by characteristic curves [16]. Each of the three rotation direction has its own specific characteristic. In Fig. 3 the characteristic curve of the functional spine unit (FSU) L2-L3 is shown.

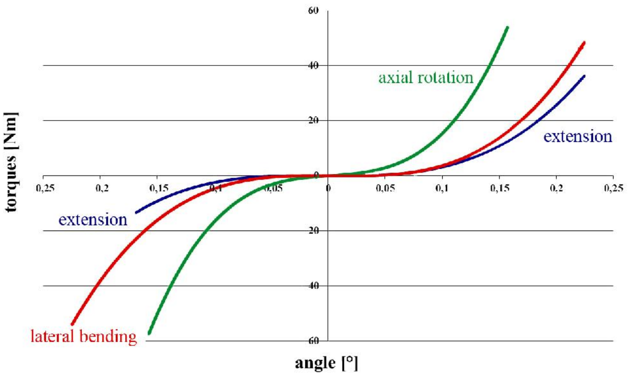

Fig. 3 Characteristic curve of the functional spine unit L2-L3

Because the individual FSU have different ranges of motion (RoM) as the FSU L2-L3, the characteristic curves of L5-Sac, L4-L5, L3-L4 and L1-L2 have been adapted according to Panjabi [17].

The biomechanical characteristic of the articular surfaces between the facet joints are modeled as 3D contact areas. During contact the facet force, acting in normal direction between the corresponding surfaces, prevents the penetration of the surfaces. For this contact force a rectangular range on the articular surface with an allowed depth of penetration is defined. In relation to the depth of penetration Δr and the velocity Δr' the following contact force is built:

$$\begin{pmatrix}F_y\\ F_y\\ F_y\\ F_x\\ F_z\end{pmatrix} = \begin{cases} c_y \cdot \Delta r + d_y \cdot \Delta r' : & c_y < 0;\ \Delta r < 0;\ \Delta r' < 0\\ c_y \cdot \Delta r : & c_y < 0;\ \Delta r < 0;\ \Delta r' > 0\\ 0 : & c_y < 0;\ \Delta r > 0;\\ 0 & \\ 0 & \end{cases} \qquad (2)$$

The parameters stiffness c_y and damping d_y are determined by a sensitivity analysis. It was here the premise that facets carry a load of 14% [18].

All vertebral bodies are not only connected by intervertebral disc and facet joints but also by surrounding ligamentous structures. The model described here includes the ligaments lig. longitudinale posterius (PLL), lig. longitudinale anterius (ALL), lig. flavum (LF) and lig. interspinale (ISL) as well as the lig. supraspinale (SSL), the lig. intertransversarium (ITL) and the capsular ligaments (CL). All these ligaments have a characteristic initial length. If a ligament is stretched due to a movement of a vertebrae, they produce a reaction force following the specific characteristic curves (Fig. 4) [15].

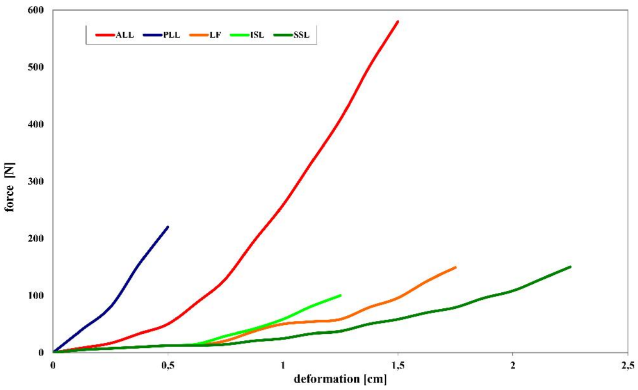

Fig. 4 Characteristic curve of the ligaments

Broad ligamentous structures, such as the posterior longitudinal ligament are realized by correspondingly more fiber bundles.

C. *Validation of the model*

It should be noted that for the validation process results the difficulty of developing a suitable method, which confirm the accuracy of the modeling. An established method is comparing the obtained results with results from accepted publications. But it has to be mentioned that not always all parameters are published, which may have a significant influence on the result. Therefore, further parameters and studies are required.

The model validation was performed by comparing the simulation results with FE results and in vivo data from literature [19], [20], [21], [22]. In Fig. 5 the pressure in the discs of the different FSU is shown.

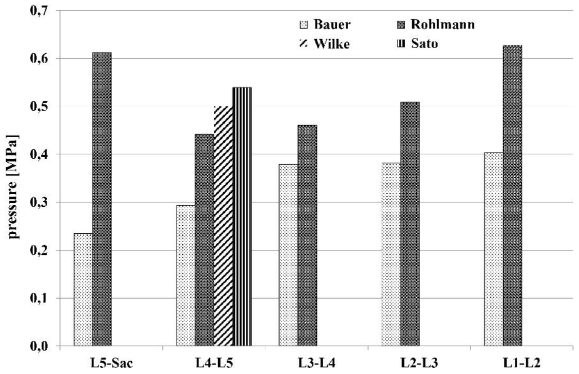

Fig. 5 Comparison of MBS-model simulation results with FE-model and in vivo experimental results of the disc pressure

The results of the pressure in the FSU are not exactly in the same order of magnitude. Especially the differences in the results of pressure in the functional spine units L5-Sac received by MBS modeling (Bauer) comparing to FE modeling (Rohlmann) are obvious. The reason may be the use of different data for the cross section areas of the intervertebral disc L5-Sac in the models. A far more decisive role for the vertical forces of the intervertebral disc plays their alignment. If the force vector of the external force acts not perpendicular to the intervertebral disc, the reaction force of the intervertebral disc is split into a vertical force component and a horizontal force component relative to the intervertebral disc. The higher inclination value of the intervertebral disc, the smaller the vertical component and the greater the horizontal component force of the intervertebral disc. In the presented MBS-model particularly the intervertebral disc of the FSU L5-Sac is strongly inclined so that the horizontal component of the intervertebral disc force is relatively large and the vertical force component correspondingly smaller (Fig. 6).

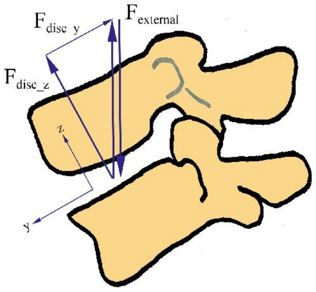

Fig.6 Components of the intervertebral disc force of the MBS-model

A further conceivable reason can be the different directions of the intersegmental rotation of the discs (Fig. 7). While in the FE-model Rohlmann all functional units perform, under the same external force, flexions, all FSU of the MBS-model Bauer perform only small movements. As a result, the discs are less loaded than in the FE-model.

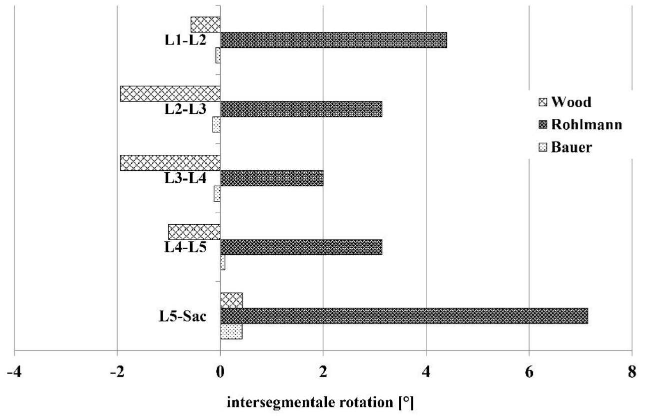

Fig. 7 Comparison of the intersegmental rotation of the discs

Comparing the forces of the facets, it can be seen that the load on the FSU L5-S1 to L4-L3 are in the same order (Fig. 8). A larger deviation arises in the FSU L2-L3 and L1-L2. The facet joints of the FSU L2-L3 of the FE-model are twice as heavily loaded as the MBS-model. The facet load of the FSU L1-L2 in the MBS-model is low, because the facet surfaces move nearly parallel to the direction of movement of the two corresponding vertebral bodies and thus have just little contact with each other. A correspondingly small contact force is build up in the facet joints.

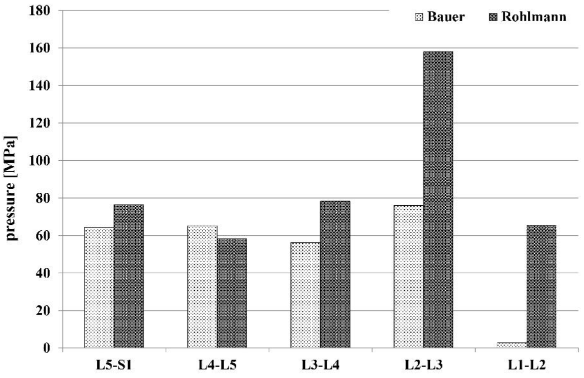

Fig. 8 Comparison of the facet forces

D. Realization of the different load cases

To analyze the effects of different load cases on the spinal structures, an external force is applied in vertical direction on the top of the surface of vertebra L1. The external force F_{ex} = 500N, which corresponds to the weight of the upper body, is suggestive increased about 100N, till an external force of F_{ex} = 1000N is reached.

III. RESULT

In all load cases the external force F_{ex} causes small movements in the spinal structures and they get out of balance, until a new equilibrium state is reached.

A. Intervertebral disc

In general, the intervertebral discs are deformed by the external force with a certain deformation velocity and develop a correspondingly reaction force. From equation (1) follows, that the higher the deformation and the deformation velocity of the intervertebral disc, the higher the disc force.

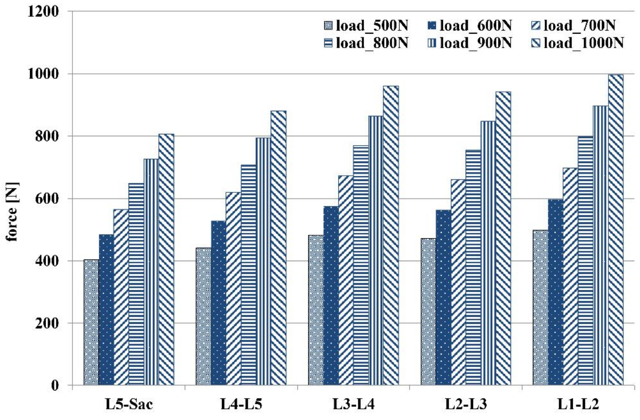

Fig. 9 Vertical components of the intervertebral disc force

Considering the intervertebral disc loads within an FSU, it can be seen that with increasing external force also the disc force increases (Fig. 9). The loading of the disc is proportional to the external force. With an increase of the external force, for example by 20% (from 500N to 600N), the disc loading in all the FSU is increased by the same percentage.

Comparing the disc loading between the individual FSUs, the disc forces of the two lowest FSUs (L5-Sac, L5-L4) are almost identical. The reaction force increases in all FSUs L3-L4. In the transition region of the lower lumbar lordosis to the upper lumbar lordosis the intervertebral disc force of all FSU L2-L3 decreases in all load cases. One possible reason could be the between the FSUs L4-L5 and L3-L4 changed direction of intersegmental rotation, from flexion to extension. The amount of the reaction force of the upper disc L1-L2 corresponds to the amount of the external force. This results from the fact that the line of action of the vertical disc force component is almost identical to the line of action of the external force.

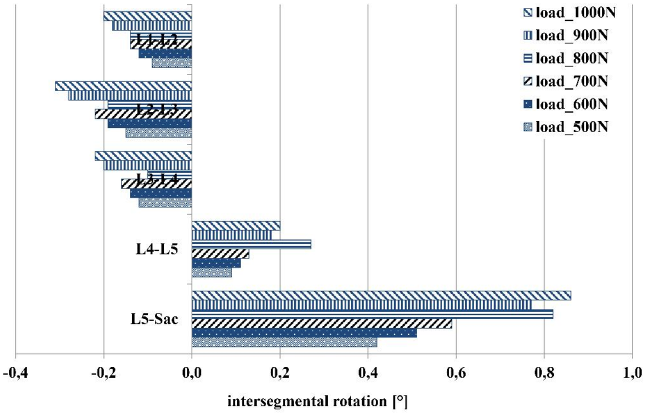

Fig.10 Intersegmental rotation of the FSUs

Fig. 10 shows the intersegmental rotations of the five FSUs during different load cases. Positive values indicate flexion and negative values extension movements. The flexion movement of the disc is characterized by a ventral directional rotation and the extension by a dorsal directed rotation. Evident is the change in rotational direction between the FSU L4-L5 and L3-L4, where also the apex is located. The lower two FSU rotate in the ventral direction and the following three in dorsal direction. The lowest FSU L5-Sac has the highest rotation values.

Generally it should be noted that the intervertebral discs perform only very small rotational movements, which is suspected in the case of a well-balanced spine.

B. Facet joints

The biomechanical behavior of the facet joints is like followed: The facet loads within an FSU, increase with increasing external force (Fig.11). The loading of the facets is proportional to the external force. In the above situated FSU L2-L3 the load increases in these facets. In the top FSU L1-L2 the facet load drops to an extremely small value. This can be explained with the fact that the facet surfaces are oriented nearly parallel to the acting external force. The facet areas of the corresponding vertebral bodies are only in very small contact and as a result of this a very low contact force is build.

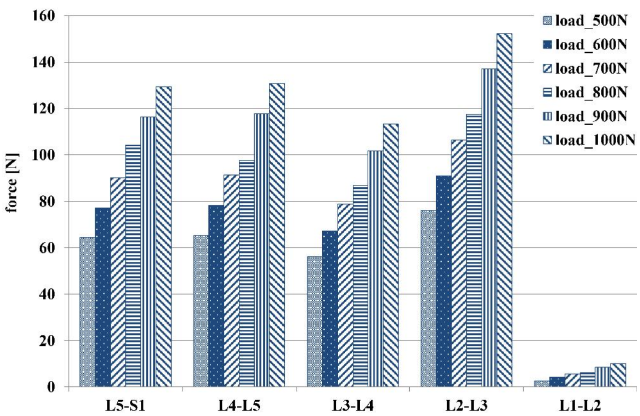

Fig. 11 Load situation of the facet joints

IV. CONCLUSION

Based on the results of this research can be concluded that in the case of a well-balanced spine, increasing external force causes a harmonic increase in loads in the spinal structures. It should be noted that in an altered alignment the biomechanical behavior may be different. For example, we showed in [23] that with variation of the spinal alignment and keeping the input parameters constant, the modified spinal curvature has a significant effect on the load distribution of the spinal structures.

Furthermore we would like to underline the importance of the validation process of a computer model. The validation of this model is not to be regarded as complete, but is carried forward in follow-up studies by sensitivity analyzes. The aim will be to verify the influence of the individual biomechanical parameters.

Because the MBS load calculation obliged with very short computation times, in a further step the impact of obesity on a well-balanced spine will be analyzed. For this purpose, a full-body model is created that includes detailed modeled spinal structures. The entire model will consist of a sub-model, that means a surface model of the body segment including their specific anthropometric characteristics and a detailed lumbar spine model. In addition, the idea is pursued to create a hybrid model that consists of MBS- and FE-elements.

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REFERENCES

[1] G. B. J. Andersson, “Epidemiological features of chronic low-back pain.” *Lancet,* vol. 354, 1999, pp. 581-585.

[2] A. Rohlmann, T. Zander, M. Rao, G.Bergmann, “Applying a follower load delivers realistic results for simulating standing.” *Journal of Biomechanics,* vol. 42, no. 10, 2009, pp. 1520-1526, doi:10.1016/j.jbiomech.2009.03.048.

[3] A. Rohlmann, L. Bauer, T. Zander, G. Bergmann, H.-J. Wilke , “Determination of trunk muscle forces for flexion and extension by using a validated finite element model of the lumbar spine and measured in vivo data.” *Journal of Biomechanics,* vol. 36, no. 6, 2006, pp. 981–989.

[4] A. Rohlmann , T. Zander, M. Rao, G. Bergmann, “Realistic loading conditions for upper body bending.” *Journal of Biomechanics,* vol. 42, no. 7, 2009, p. 884–890.

[5] T. Zander, A. Rohlmann, J. Calisse, G. Bergmann, “Estimation of muscle force in the lumbar spine during upper-body inclination.” *Clinical Biomechanics*, 16 Supplement, No. 1, 2001, S73-S8.

[6] H. Schmidt, F. Heuer, U. Simon, A. Kettler, A. Rohlmann, L. Claes, H.-J. Wilke, ”Application of a new calibration method for a three-dimensional finite element model of a human lumbar annulus fibrosus.” *Clinical Biomechanics*, vol. 21, no. 4 337–344.

[7] H.-J. Wilke, et al., “Shear properties of the lumbar intervertebral disc after spondylolysis.” *European Spine Journal*, 20, 2011.

[8] J. R. Williams, R. N. Natarajan, G. B. J. Andersson, “Inclusion of regional poroelastic material properties better predicts biomechanical behavior of lumbar discs subjected to dynamic loading.” *Journal of Biomechanics*, vol. 40, no. 9, 2007, pp. 1981-1987.

[9] F. Heuer, H. Schmidt, Z. Klezl, L. Claes, H.-J. Wilke, “Stepwise reduction of functional spinal structures increase range of motion and change lordosis angle.” *Journal of Biomechanics* vol. 40, 2007, pp. 271–280.

[10] V. Goel, K. Kong, J. S. Han, J. N. Weinstein, L. G. Gilbertson, “A combined Finite Element and Optimization Investigation of lumbar spine mechanics with and without muscles.” *Spine* , vol. 18, no 11, 1993, pp. 1531-1541.

[11] F. Galbusera, H. Schmidt, C. Neidlinger-Wilke, H.-J. Wilke, “Computermethods in Biomechanics and Biomedical Engineering.”, 2011, vol. 14, no. 8, 2011, pp. 729–739.

[12] A. Rohlmann, T. Zandera, H. Schmidt, H.-J. Wilke, G. Bergmann, “Analysis of the influence of disc degeneration on the mechanical behaviour of a lumbar motion segment using the finite element method.” *Journal of Biomechanics* vol. 39, no. 13, 2006, pp. 2484–2490.

[13] P. Reimche, “Segmentierung computertomographischer Daten der Wirbelsäule“, bachelor thesis, Universität Koblenz-Landau, Germany, 2010.

[14] S. Nowack, „Visualisierung der Wirbelsäule anhand segmentierter Computertomographie-Daten zur weiteren Verwendung in SIMPACK“, bachelor thesis, Universität Koblenz-Landau, Germany, 2010.

[15] P. Roussouly, S. Gollogly, E. Berthonnaud, J. Dimnet, “Classication of the normal variation in the sagittal alignment of the human lumbar spine and pelvis in the standing position.” *Spine*, vol. 30, no.3, 2005, pp. 346-353.

[16] U. Hausen, „Entwicklung von 3D-Simulationsmodellen für die computergestützte Operationsplanung bei chirurgischen Eingriffen an der Lendenwirbelsäule.“ Phd thesis, Universität Koblenz-Landau, Germany, 2013.

[17] A. White, M. M. Panjabi. *Clinical Biomechanics of the Spine*. 2nd ed. Philadelphia, Pa: JB Lippincott Co; 1990.

[18] J. Nicolas V., W. William, C.,Winkelstein, A. Beth, “Spinal Facet Joint Biomechanics and Mechanotransduction in Normal, Injury and Degenerative Conditions.” *Journal of Biomechanical Engineering*”. vol. 133, no. 7, 2011; 71010-NaN. doi:10.1115/1.4004493.

[19] A. Rohlmann, T. Zander, M. Rao and G. Bergmann, “Applying a follower load delivers realistic results for simulating standing”, *Journal of Biomechanics*, vol. 42, no. 10, 2009, pp.1520-1526.

[20] H.-J. Wilke, P. Neef, M. Caimi, T. Hoogland, L.E. Claes, “New In Vivo measurement of pressure in the intervertebral disc in daily life.” *Spine*, vol. 24, no. 8, 1999, pp.755-762.

[21] K. Sato, S. Kikuchi and T. Yonezawa, In Vivo intradiscal pressure measurement in healthy individuals and in patients with ongoing back problems, Spine, Vol. 24, 1999, pp.2468-2474.

[22] K. Wood, P. Kos, M. Schendel, K. Persson, “Effects of position on the sagittal-plane profile of the thoracolumbal spine”, *Journal of spinal disorders*, vol. 9, no. 2, 1996, pp. 165-169.

[23] S. Bauer, “Effects of Individual Spine Curvatures - A Comparative Study with the Help of Computer Modeling”, *Biomedical Engineering.* ISSN (Online) 1862-278X, ISSN (Print) 0013-5585, DOI: 10.1515/bmt-2012-4052, September 2012.

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