Development of a Human-Seat Cushion Finite Element Model for Sitting Comfort Analysis

Xianxue Li[1,2], Li Ding[2(✉)], Xianchao Ma[1], Baofeng Li[1], and Haiyan Liu[1]

[1] Shanghai Aircraft Design and Research Institute, No. 5188 JinKe Road, Pudong New District, Shanghai 201210, China

[2] Key Laboratory for Biomechanics and Mechanobiology of Ministry of Education, School of Biological Science and Medical Engineering, Beihang University, No. 37 XueYuan Road, Haidian District, Beijing 100191, China

li36l0ll20@l26.com

Abstract. With the development of civil aviation market, more and more people travel by plane and sitting comfort during the flight attracts increasing attention. In this study, a biomechanical human-seat cushion finite element model with spine, pelvis, thigh, buttocks and seat cushion was established along with seat comfort experiment to study the sitting comfort. The results show similarity in both pressure distribution and value between simulation and experiment. So the finite element model was validated.

Keywords: Civil aviation · Finite element · Comfort

1 Introduction

With the development of civil aviation market, more and more people travel by plane and sitting comfort during the flight attracts increasing attention. So it's very important to find how to evaluate the sitting comfort during the flight in order to supply more comfortable flight experience for the passenger.

In this study, a biomechanical human-seat cushion finite element model with spine, pelvis, thigh, buttocks and seat cushion was established along with seat comfort experiment to study the sitting comfort. The finite element model is based on a standard Chinese pilot's computer tomographic scan.

2 Methods

Firstly, a volunteer that fit the 50th percentile Chinese male's dimensional data was recruited and the informed consent was obtained. CT scans from T1 to pelvis and femur were obtained and then imported in Mimics software to reconstruct the geometry of spine, pelvis and femur.

For each piece of bone, such as vertebrae, hip, femur and so on, the initial geometry models were imported into reverse engineering software Geomagic Studio 2013 to

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construct a detailed geometric model. In this step, poor quality triangular facet was remodified and the geometry was smoothed and optimized. Then we get the non uniform rational B spline (Nurbs) surface model, the surface model is saved as *.iges format to be meshed by finite element mesh generation method in Hypermesh. The Nurbs surface model of vertebrae, sacrum, hip and femur is as shown in Fig. 1.

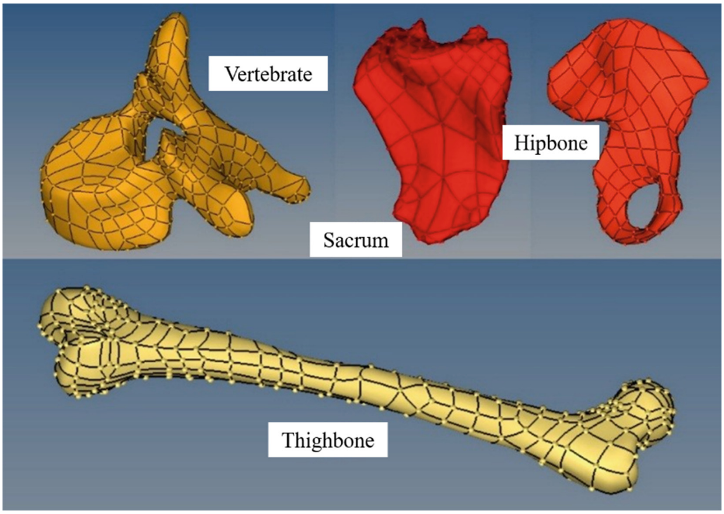

Fig. 1. Nurbs surface model of the bone

Then the above established Nurbs surface models were imported into the finite element pre-processing software Hypermesh 12. The Nrubs surface model contains only a layer of the surface and is not solid, therefore, the first step was to generate entity model, then the 3D finite element mesh was generated. The skeleton model was meshed in 4 node tetrahedron element, and the element size was about 5 mm for the vertebrae, 10 mm for the hip and femur.

The intervertebral disk model was generated based on the part of adjacent vertebral endplate in Hypermesh. Firstly the Nurbs surface model on the adjacent vertebral endplate surface part was extracted based on the upper and lower surfaces of intervertebral disk endplate and enclosed intervertebral disk surface model was generated. Finally, the surface model of the intervertebral disk was filled and 3D finite element model was generated. The model of intervertebral disk was divided into 4 node tetrahedral elements, and the size of the element was about 3 mm. The finite element models of bone and intervertebral disk were shown in Fig. 2.

In this study, the geometry model of the hip and thigh soft tissue was established based on a previous 3D geometry model of the human body. Part of the 3D model of human body was rotated to sitting posture after segmentation and the Nurbs surface model of the sitting human body was generated. The process of establishing the sitting posture human body model is shown in Fig. 3. The 3D finite element mesh model was shown in Fig. 4.

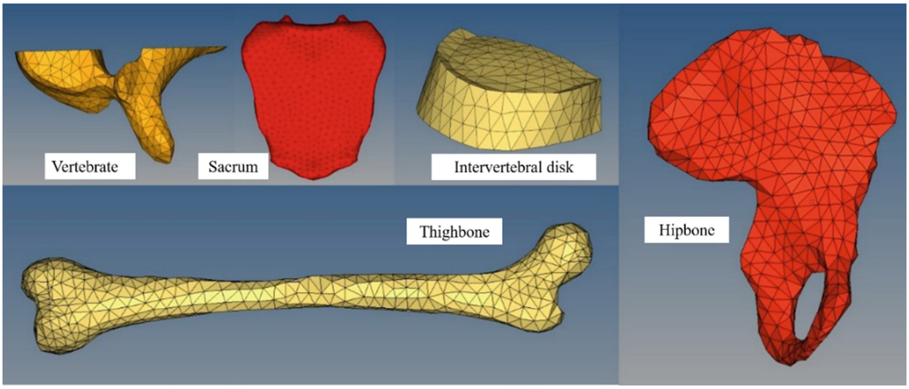

Fig. 2. Finite element model of the bone and intervertebral disk

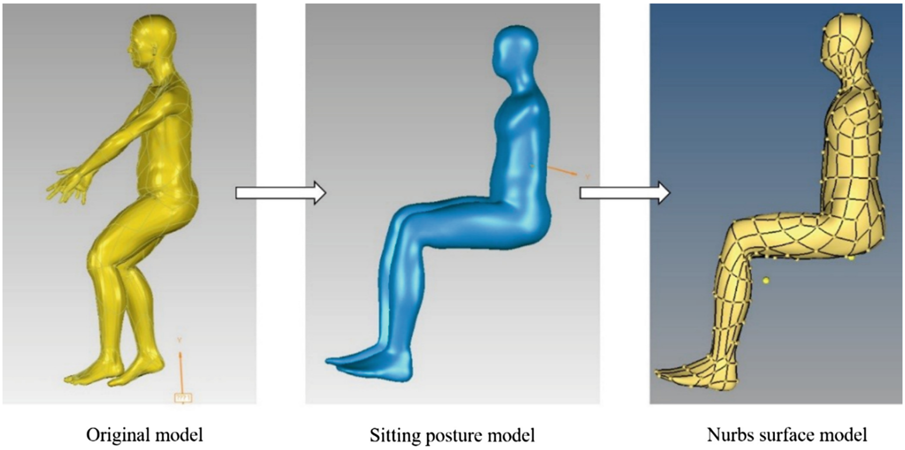

Fig. 3. Process of establishing sitting posture human body model

There are main 7 ligaments around the spine winch are relative with the spine's movement.

The seat cushion model was meshed in four layers with 8-nodes elements. The other parts of human such as head, neck, limbs and trunk were modeled by mass point and connected with relative vertebra and femur bones. The mass of each vertebra segmental of the human truck referred Pearsall's work (Pearsall et al. 1996). Ligaments on the spine were modeled using axial elements and their stress-strain relationship referred Shirazi-Adl's work (Shirazi-Adl et al. 1986).

Since the whole human model consists different body parts and the method of establish is different that different body parts have different coordinates, so the assembly of different body parts is an important work. The assembly consists of location and

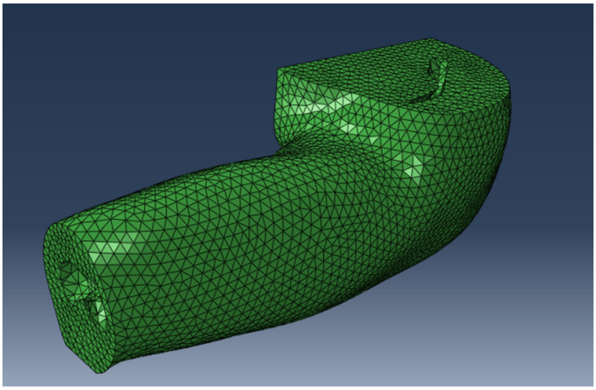

Fig. 4. Finite element model of hip and thigh

constraint relationship. The assembly of location is performed in Hypermesh and the assembly of restraints is performed in ABAQUS.

The mass points of head, neck and upper limb segment were constrained by beam element with the reference point of T1 vertebral endplate. The constraints between the vertebra and the various mass points of the trunk segments were defined as follows: firstly a reference point in front of each vertebrae center position was established that this reference point was constrained with the outer nodes of relative vertebrae through rigid coupling, then the reference points were connected with relative mass points of the truck segments by beam element, so the weight of each truck segments was applied to the corresponding vertebrae.

The contact surface between the vertebrae and the intervertebral disc is set as a tie constraint. According to the anatomical relationship, the appropriate nodes are selected on the sacrum and the hip bones. The hip, femur, thigh and hip are also set as tie constraint.

The constitutive laws for the bones in the model are considered as linear elastic. The intervertebral discs are modeled using a Mooney-Rivlin hyperelastic model which is expressed in the form of the polynomial strain energy potential. The soft tissue was modeled using a non-linear visco-hyperelastic material model. A second order polynomial strain energy potential was used to describe the hyperelastic portion. The viscoelastic portion was described by the Prony-series model and the viscoelastic parameters were set as $G_1 = 0.05$, $K_1 = 0.5$ and $\tau_1 = 0.8\,\mathrm{s}$. Seat cushion was assumed to be made of SAF 6060 polymer foam with rate-independent hyperelastic and viscoelastic behaviors. The hyperelastic portion of the seat cushion is expressed in the form of the second order Odgen strain energy potential and the viscoelastic portion is expressed by the Prony series.

The established whole finite element model is shown in Fig. 5.

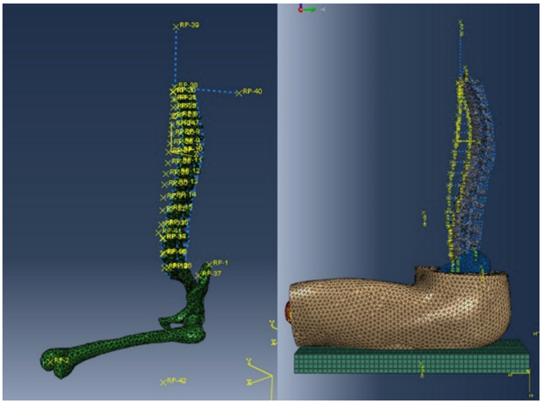

Fig. 5. The whole finite element model

3 Validation and Conclusion

Finally, seven volunteers with mean weight: 64.4 kg which were similar with the human model were recruited to perform the sitting pressure experiment. Then the sitting pressure distribution between simulation and experimental results were compared and the results shows similarity in both pressure distribution and value, as shown in Fig. 6.

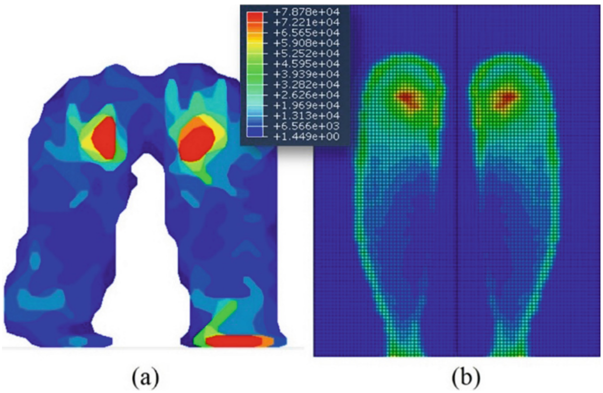

Fig. 6. Sitting pressure distribution (a) experimental result; (b) simulation result.

Based on previous analysis, we can think the finite element model is validated at this point.

References

Shirazi-Adl, A.A., Ahmed, A.M., Shrivastava, S.C.: Mechanical response of a lumbar motion segment in axial torque alone and combined with compression. Spine **11**, 148–163 (1986)

Belytschko, T., Schwer, L., Privitzer, E.: Theory and application of a three-dimensional model of the human spine. Aviat. Space Environ. Med. **49**, 158–165 (1978)

de Looze, M.P., Kuijt-Evers, L.F., van Dieen, J.: Sitting comfort and discomfort and the relationships with objective measures. Ergonomics **46**, 985–997 (2003)

Dooge, D., Cabane, C., Marca, C., Dwarampudi, R., Cohen, D., Pearson, S.: Utilizing finite element tools to model objective seat comfort results. SAE International (2012)

Grujicic, M., Pandurangan, B., Xie, X., Gramopadhye, A.K., Wagner, D., Ozen, M.: Musculoskeletal computational analysis of the influence of car-seat design/adjustments on long-distance driving fatigue. Int. J. Ind. Ergon. **40**, 345–355 (2010)

Bhonge, P.S., Thorbole, C.K., Lankarani, H.M.: Computational modeling and performance evaluation of a dax-foam aircraft seat cushion utilizing high loading rate dynamic characteristics. In: ASME 2010 International Mechanical Engineering Congress and Exposition (2010)

Makhsous, M., Lim, D., Hendrix, R., Bankard, J., Rymer, W.Z., Lin, F.: Finite element analysis for evaluation of pressure ulcer on the buttock: development and validation. IEEE Trans. Neural Syst. Rehabil. Eng.: Publ. IEEE Eng. Med. Biol. Soc. **15**, 517–525 (2007)

Pearsall, D.J., Reid, J.G., Livingston, L.A.: Segmental intertial parameters of the human trunk as determined from computed tomography. Ann. Biomed. Eng. **24**, 198–210 (1996)