

Challenge of Lumbar Support Design Using Human Body Models

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ABSTRACT

Both experimental and numerical simulations were attempted to investigate postural changes of sitting occupants such as seat back pressure distribution and lordotic curvatures of lumbar spine with the different configurations of lumbar support. Using the detailed anatomical digital human body models, a fairly good quantitative prediction on the increase and transfer of peak pressure to lumbar region and the lordotic curvature raise of the lumbar spine as the support prominences was obtained.

INTRODUCTION

Objective of this study is to analyze changes in seat back pressure distribution and lumbar spine curvature of occupant according to variations of the lumbar support height and prominence using digital element human body models. As seating and riding comfort is a key issue for vehicle interior design, numerical simulation including human body models helps overcoming the limitations of experimental studies, and quantifying subjective comfort sensations. There is also pressing demand for up-to-date human body models reflecting the recent anthropometric data. Authors have presented series of papers regarding the digital human body models for riding comfort simulation at Digital Human Modeling Conference [1-4] and this study is one of practical applications to the automotive seat design practice.

Three digital human body models, 5th %tile female, 50th %tile male, and 95th %tile male with recent anthropometric database have been developed and validated against volunteer test results such as seating pressure distribution and buttock deformation. And furthermore, the effects of lumbar spine support on physical changes of occupants, such as contact

pressure and lumbar spine curvature were numerically and experimentally quantified. The peak seat back pressure increases and shifts to the lower back with the lumbar support prominence. A pivot point (e.g. T12 for 95th %tile male) on the sagittal plane of trunk with respect to the curvature change was also identified with the increase of lumbar support prominence. The lumbar spine curvature was quantified with different lumbar support prominences. Consequently, internal and external posture changes of occupants regarding to the different lumbar support configuration were investigated and thus a better understanding for the biomechanics of occupant seating was obtained.

There was couple of recent paper presentations regarding the biomechanics of lumbar spine in the automotive sitting. Zenk et al [5] tried to correlate a spinal load with an ideal seat position. They employed a volunteer to measure the intervertebral lumbar disc pressure by implanting pressure sensors and found out the ideal seat setting at which the measured disc pressure became a minimum. Frohriep et al [6] also reported that their research studies have shown that lumbar spine apex angles in fully protruded lumbar position averaged at 173°, thus a mildly extended posture. Both of these studies were experimental investigations and thus limited by various conditions since live human subjects were directly involved. Utilizing digital human body models would help us to overcome such a restriction when the model are verified and validated against the real human subjects.

This research also could help to find out discomfort factors in the lumbar support design if the further correlation with the comfort rating for various lumbar support designs would be accomplished.

DIGITAL HUMAN BODY MODELS

Three digital human body models, 5th %ile female, 50th %ile male, and 95th %ile male based on statistical analysis of recent North American anthropometric database were developed as shown in Fig. 1[1]. The models were built by scanning the precise exterior and interior geometries of human subjects in driving positions and they consist of detailed anatomical skeletal structures and fleshes made of various kinds of 1D to 3D finite elements to represent postural changes and tissue deformation of occupants in automotive sitting context. The three digital human body models were rigorously validated against volunteer tests such as seating pressure distribution and buttock deformation. Fig. 2 shows a typical measurement setup of body pressure distribution on a raw polyurethane foam pad (hexahedron in 400 x 400 x 100 (30) mm for the cushion (back)) of the 50th %tile subject sitting in the package layout of a medium size sedan. The subject was asked to take a comfortable posture with the given handle and pedal positions. The sitting pressure distributions on both cushion and back were measured by using a pressure sensor system (X-sensor, 43x43 cells). A thin sheet layer of plaster cast (3M's Scotch cast) was also placed between the buttock and raw PU foam pad in order to measure the deformed shape of buttock. The pattern of body pressure distribution in a sitting position is generally known to be closely dependent on the posture of the occupant subject such as torso-hip and hip-thigh angles. Therefore, the sitting positions of the subjects were minutely measured by an optical sensor system (MotionAnalysis, Model: Eagle 4).

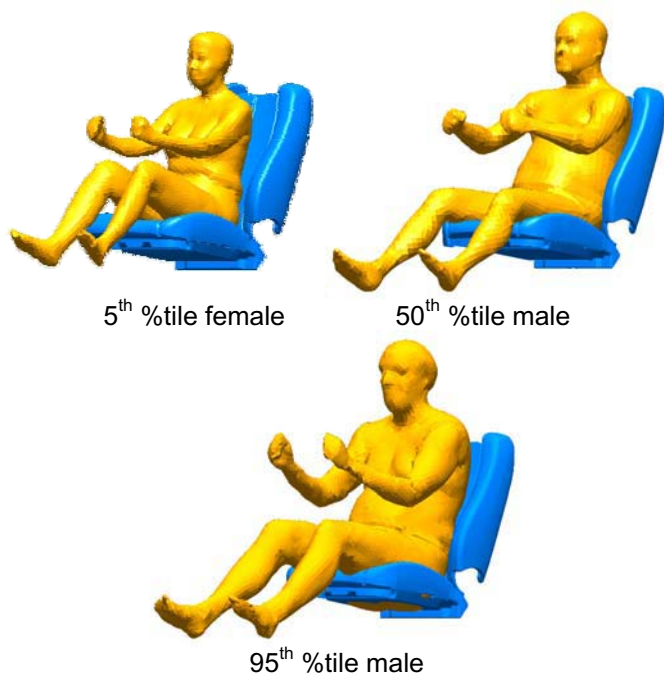


Fig. 1 North American standard human body models [1]

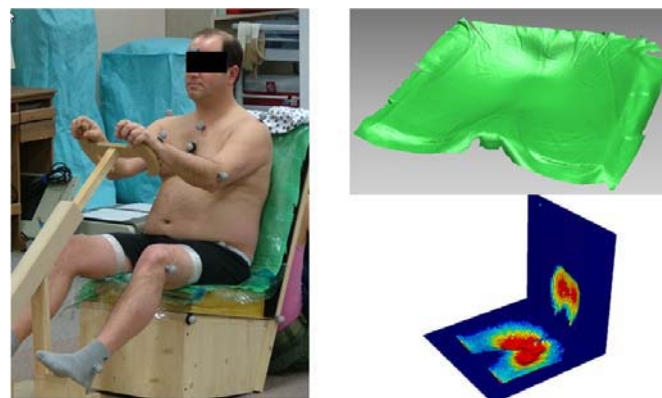


Fig. 2 Experimental set up for human body modeling validations (left: 50th %tile male volunteer sitting on raw PU foam in driving posture, top right: plaster band for the measurement of buttock deformation (Scotch cast), bottom right: body pressure distribution (X sensor)

Applying a gravity load into the digital human body model, a simulation of seating process was performed. The PU foam block in Fig. 2 was modeled by a highly compressible, non-linear elastic material. The material characteristics were determined through a preliminary compression tests on a foam coupon specimen. A non-linear contact algorithm with friction (Coulomb's law) was used at the interface with the human model. The horizontal (U_x) and vertical (U_z) translations of the wrist and the ankle joints of human body model were fixed to meet the geometric packaging requirement of the vehicle layout. The head was constrained only for the horizontal translation (U_x) and the pitching (R_y) but free to move in other directions to maintain the natural eye position. The sitting posture of the digital human body model, e.g., 50th %tile model is shown in Fig. 3 and the percentile errors in three dimensional distances of each marker between simulation and experiment listed in Table 1 indicate a good correlation.

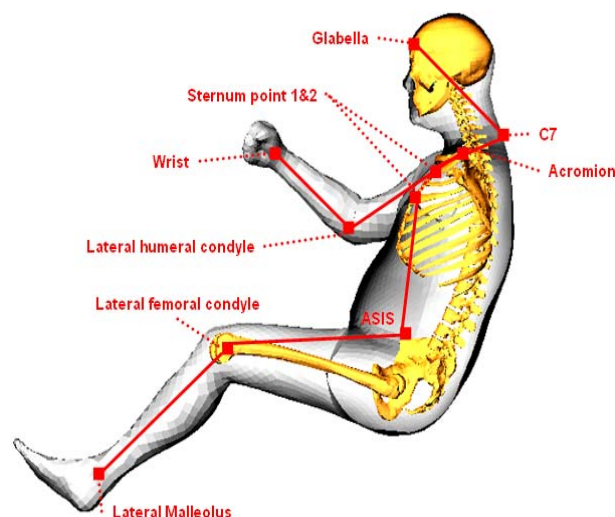


Fig. 3 Simulated seating posture of FE human body model (50th %tile male)

Table 1 Percent errors in 3D distances of markers between simulation and experiment

Marker position	5 th %tile female	50 th %tile male	95 th %tile male
Glabella	5.10	1.06	0.01
C7	5.05	2.12	1.13
Acromion	1.48	2.34	0.01
Sternum point 1	N/A	1.99	1.32
Sternum point 2	N/A	1.78	5.46
Humeral condyle	7.31	2.24	8.50
Wrist	4.30	0.24	0.09
Femoral condyle	6.15	6.72	2.21
Malleolus	0.51	1.60	0.01

The accuracy of seating pressure distribution of FE models on cushion and back has been quantitatively analyzed and validated by comparing balance diagrams between experiment and simulation as shown in Fig. 4. Simulated contact areas and seating force ratios for cushion and back were also compared with experimental measurements and listed for the 50th %tile model in Table 2. The other two models, 5th and 95th %tile exhibited the similar level of accuracy in predicting sitting pressure distribution to those of 50th %tile model.

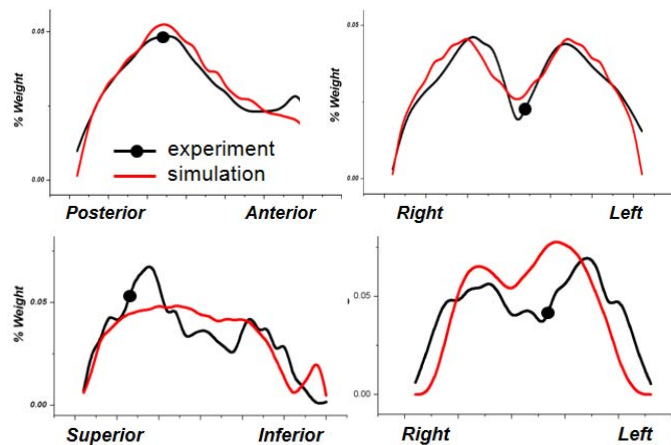


Fig. 4 Balance diagram of cushion and back pressure distribution for 50th %tile model

Table 2 Contact area and seating force ratios for 50th %tile model

Items		Exp.	Sim.	% Err.
Contact area for cushion (mm ²)		1232	1231	0.08
Contact area for back (mm ²)		692	689	0.43
Seating force ratio	Back / Total	0.263	0.265	0.76
	Cushion / Total	0.736	0.735	0.13
Sectional force ratio for cushion	Hip / Total	0.655	0.699	6.72
	Thigh / Total	0.155	0.124	20.00
	side / Total	0.190	0.177	6.84

The deformed shapes of buttock and cushion foam in finite element simulation were compared with experimental measurements. Using a thin layer of plaster cast, the deformation of buttock in sitting posture was measured and its digitized profile was included in the simulation result for a visual comparison as shown in Fig. 5. In order to quantify the accuracy of model

prediction on the deformed buttock shape, six cutting planes in XZ and YZ plane were applied. The cutting lines were selected so that they could pass by sagittal center and ischial tuberosities. The difference of simulated model prediction for the buttock deformation compared to the experimental measurement was quantified by calculating the vertical distances of deformed shapes in six cutting planes from the corresponding datum lines in the initial (undeformed) cushion foam. The percent errors for three models were ranged in 3.0%~14.5%.

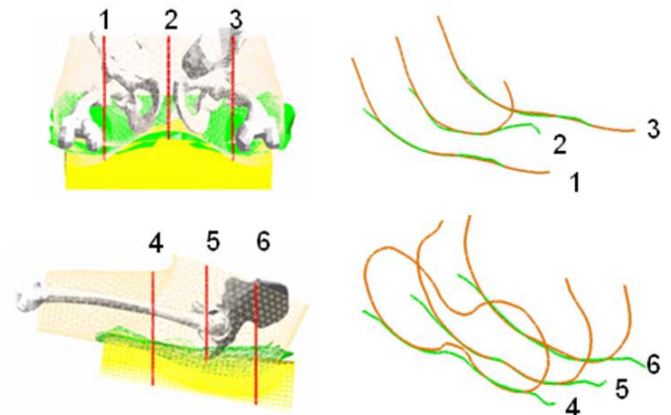


Fig. 5 Deformed shapes of buttock and cushion foam (Top: 3 cuttings (1, 2, 3) in XZ plane, Bottom: 3 cuttings (4, 5, 6) in YZ plane)

VOLUNTEER TEST WITH LUMBAR SUPPORT

Simple test jig for the volunteer measurement on lumbar support was designed and built as shown in Fig. 6. Four wood blocks with different thicknesses i.e. prominences in cylindrical arc shape were placed in turn on seat back at various heights by mimicking the adjustable real lumbar support in a car seat. Since the wood block has no compliance, the supporting loads on the lower back would not be equivalent to those from flexible lumbar supports in real car seats with corresponding prominences.

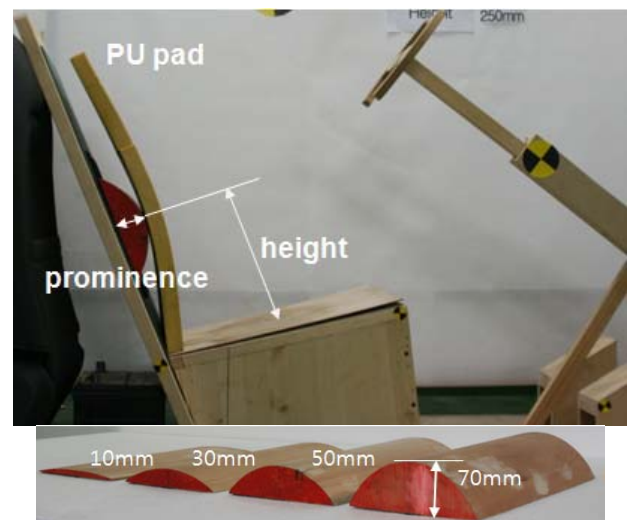


Fig. 6 Test jig for lumbar support test