

Development of a Detailed Buttock and Thigh Muscle Model for the Dynamic Occupant Model CASIMIR

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ABSTRACT

For the evaluation of seats under comfort and health aspects by means of a Finite-Element (FE) simulation a detailed static and dynamic occupant model is required. The occupant model CASIMIR, which is presented here, in combination with seat model was used in different comfort simulation projects where a good correlation to measurements - seat pressure distribution and transfer function - was found.

In order to increase the accuracy of results for internal quantities e.g. the load on the intervertebral disks, CASIMIR was enhanced to improve the force transmission from the seat to the human body. Due to the consideration of the different tissues by corresponding material parameters and the modelling of the filamentary force transmission via springs and dampers for muscles, the human anatomy is modelled more realistically.

INTRODUCTION

In the automotive development process the numerical simulation obtains a more and more decisive role due to the cost and time efficiency aspects. Various publications [1,2,3] are available describing its application also for seat comfort simulation. Thereby the computation of important quantities such as seat pressure distribution and seat transfer function is only possible with the use of an occupant model. Simulations using the human model CASIMIR here presented, combined with a static and dynamic validated seat model thereby have shown good correlations to measurements [4].

Within these projects CASIMIR was mainly implemented to consider the realistic load case for the seat, which is the human body with its static and dynamic properties. Thereupon only an evaluation using measures on the seat was carried out. In a further step of this virtual development procedure the informational value should be extended to measures of the occupant itself, such as internal forces acting on the lumbar spine, causing low

back pain. This allows for an enhanced evaluation of the health effects, which is very important especially for operators of commercial vehicles. Furthermore this represents the required basis for investigations, relating subjective sensitivities of test drivers to physical quantities.

In order to increase the accuracy of these occupant results, CASIMIR was enhanced by a detailed buttock and thigh model, to improve the force transmission from seat to body. Thereby the human body properties have been divided into two parts. A continuum model representing the existing tissues such as fat and muscles has been implemented, mainly reflecting the compressive behaviour. Additionally the filamentary force transmission of the muscles is modelled via discrete spring and damper elements. The following chapters describe the setup of the enhanced model CASIMIR and show its influence on the computation of comfort relevant quantities such as seat pressure distribution and apparent mass.

CONTINUUM MODEL

As mentioned before, the enhanced continuum model mainly serves to implement the compressive tissue behaviour. Thereby the properties of the different human tissues such as fat, muscles and skin must be considered. Compared to the homogenous model already existing this represents a more anatomical approach and so results with an increased accuracy are expected.

INPUT DATA

In the first step of the model setup the volumes of the different tissues must be identified. As input data the results of the Visible Human Project [5] are used. Object of this project was a detailed visualisation of the human anatomy via computer tomography and magnet resonance tomography pictures. Additionally the body donor (human male, 187 cm, 90 kg) was cut in slices,

with a thickness of 1 mm, from each a photo has been taken.

Due to their better contrast between the different tissues, these photos are used for the model setup. The processing of the photos is carried out with the software SCAN-IP [6]. After importing the data into the programme, the cross-sections are segmented considering the different thigh and buttock muscles (Figure 1).



Fig. 1: Segmented 2D Cross-Section Thigh Muscles

Finally the 3D geometries are generated by assembling the segmented 2D cross-sections. Artificial effects through the manual segmentation have been eliminated by resampling the used data (see Figure 2). This surface generation has been carried out only for the muscles, as the fat tissue results out of their interspace.

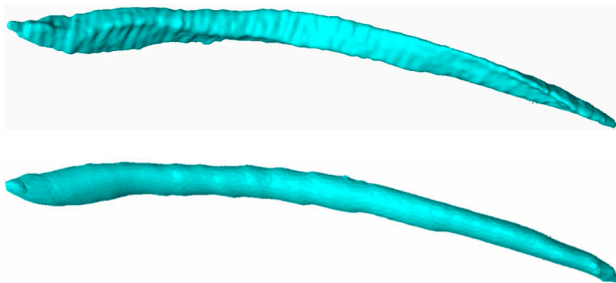


Fig. 2: 3D Original and resampled of *M.sartorius*

FE-MODEL

Afterwards, the muscle volumes are imported into the pre-processor HYPERMESH [7]. As in the first step CASIMIR is extended to the percentile m50, the geometries must be scaled. The boundaries for adjusting the data to percentile m50 are given by the code DIN 33402 [8]. Furthermore the muscles of the buttock must be adjusted as the CASMIR model is sitting whereas the body donor was lying. Figure 3 exemplarily shows the different states before and after the adjustment of the *M.gluteus maximus*.

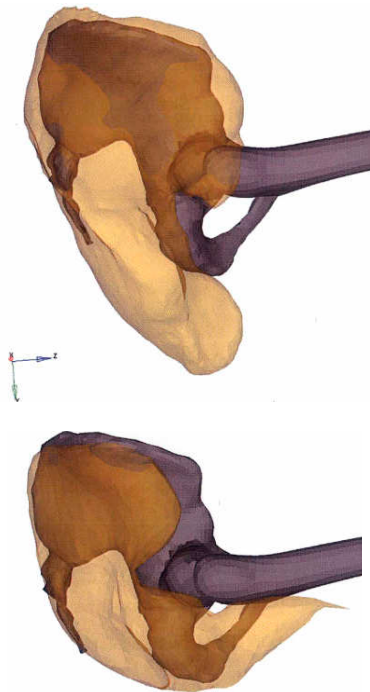


Fig. 3: *M.gluteus maximus* before and after adjustment due to change of posture

The mesh is generated with linear tetrahedron elements. Considering the computation time, the number of degrees of freedom (dofs) is limited, whereby a typical element size of about 20 mm is chosen for the elements. Consequently, small fat volumes between the muscles are neglected. Furthermore very small muscles are assembled to one volume. Figure 4 shows the CASIMIR model including the extended buttock and thigh continuum model. The fat tissue is illustrated transparent.

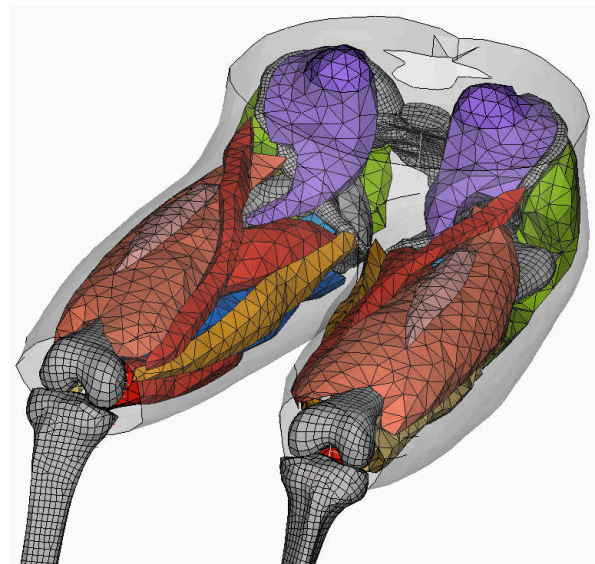


Fig. 4: Continuum model of thigh and buttock

MATERIAL MODEL

From different publications [9, 10] it is known that the human tissue shows a non-linear behaviour. Accordingly a hyperelastic material law after Mooney-Rivlin (Equation 1.), describing the strain energy potential U , applies.

$$U = C_{10} \left(\bar{I}_1 - 3 \right) + C_{01} \left(\bar{I}_2 - 3 \right) + \frac{1}{D_1} \left(J^{el} - 1 \right)^2$$

Equation 1: Strain energy potential formulation

With:

- C_{10} and C_{01} defining initial shear modulus;
- D_1 defining the bulk modulus;
- I_1 and I_2 as the first and second strain invariants;
- J^{el} as the volume ration;

The free parameters C_{01} and C_{10} are defined after literature. Although in some publications it is shown that the fat tissue behaves stiffer than the muscle tissue, the model here presented is contrary. This procedure assumes that the muscles are activated while seating which induces a stiffening effect of the tissue. Figure 5 shows the material behaviour of a one-element-model for the muscle and fat tissue under a force driven loading.

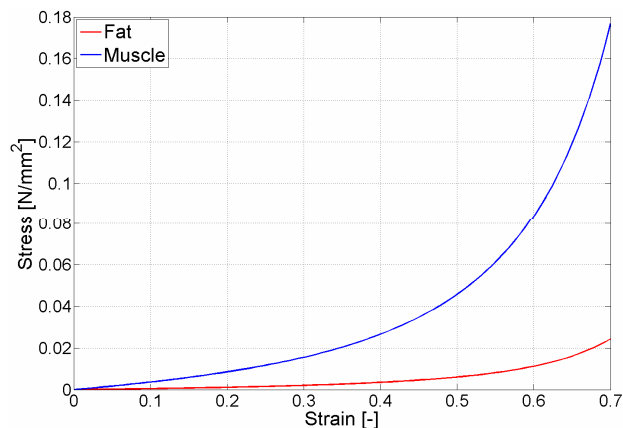


Fig. 5: Material behaviour of fat and muscle tissue computed with a deflection loaded one-element-model

The viscous material properties are defined frequency-dependent over the storage and loss modulus based on literature values.

DISCRETE MUSCLE MODEL

As the implementation of the filamentary force transmission of the muscles by a continuum model is very complex, a simplified approach using discrete spring and damper elements is applied. In the actual setup this approach represents only the filamentary force transmission and has no direct influence on the properties of the continuums model.

Through its activation, the musculature of buttock and thigh has different functions. On the one hand the muscles are activated to adjust and afterwards stabilise the actual posture. Beside the stabilisation of the hip and knee joint this includes especially the erection of the upper body by the *M.psoas major* by adjusting the pelvis rotation. On the other hand the human body response behaviour due to dynamic excitation is influenced by the passive and active reactions of the muscles.

Since hip and knee are modelled by kinematic couplings, i.e. ideal joints, the small local muscles are neglected. The muscles considered within the model are chosen by their influence on the following dofs of the hip joint:

- Flexion of the hip joint;
- Extension of the hip joint;
- Abduction of the thighs;
- Adduction of the thighs;
- Rotation inwards of the thighs;
- Rotations outwards of the thighs;

and on the subsequent dofs of the knee joint:

- Flexion of the knee;
- Extension of the knee;

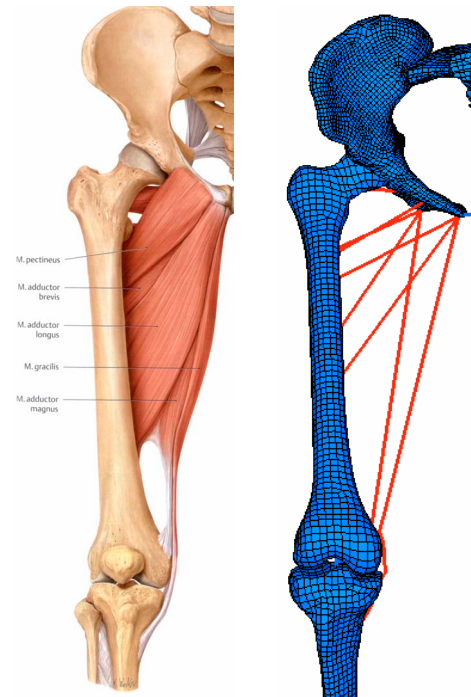


Fig. 6: Anatomical presentation of the *M.adductor magnus* and its realisation in the model

The inwards and outwards rotation of the knee is not considered as the knee is modelled by a hinge joint. This assumption is tolerable as the real movements are very small.

The identification of the relevant muscles is carried out on the basis of a standard anatomical textbook [11], where their contribution to the anatomical movements is