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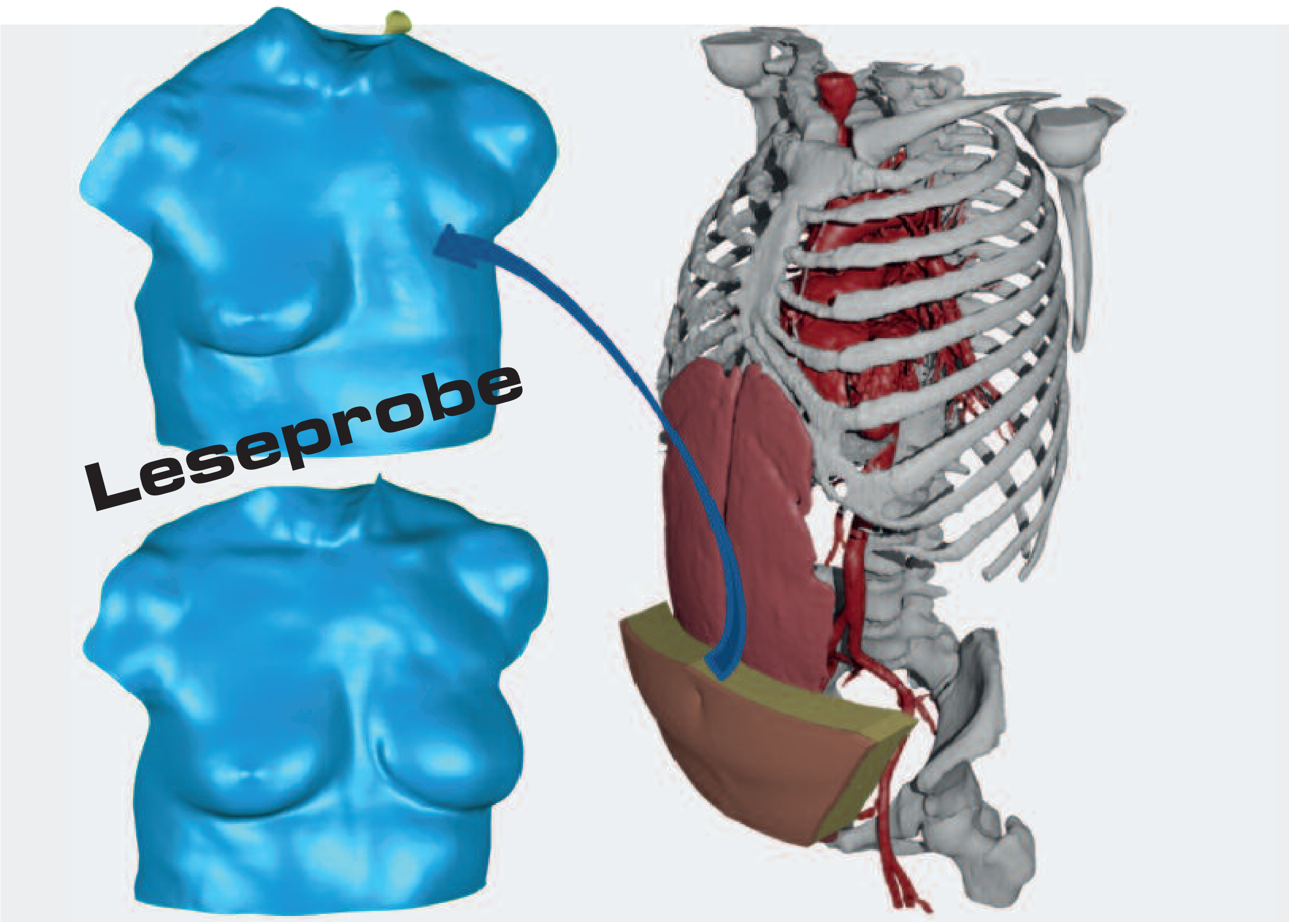

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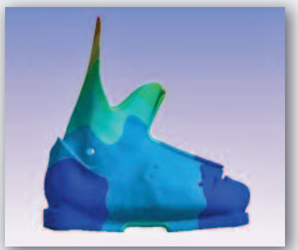

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Entwicklung eines individuell angepassten Skischuhs

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FEM-Simulation of the soft tissue of the female breast

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Inhalt

Titel
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Bild: Jalil Jalali, M. Sc. in Computational Mechanics at Technische Universität München

News

Rückblick: 18th International Symposium on Computational Biomechanics in Ulm

Seit 18 Jahren treffen sich in Ulm auf dem „Symposium on Computational Biomechanics“ Wissenschaftler aus dem Bereich Biomechanik. Im Mai 2013 folgten fast 60 Wissenschaftler der Einladung. Speziell junge Forscher haben auf dem Symposium eine hervorragende Gelegenheit, ihre neuesten Ergebnisse einem weltweiten Publikum zu präsentieren und zur Diskussion zu stellen.

Das Symposium startete mit den Keynote Präsentationen von Prof. John Rasmussen und Prof. Oliver Röhrle. Prof. Rasmussen von der Universität Aalborg zählt zu den Mitgründern der Software-Firma AnyBody Technology. Er berichtete über die Berechnung von Muskelkräften mit den Methoden der Mehrkörpersimulation. Prof. Röhrle von der Universität Stuttgart präsentierte Methoden zur Modellierung von Muskel- und Fettgewebe.

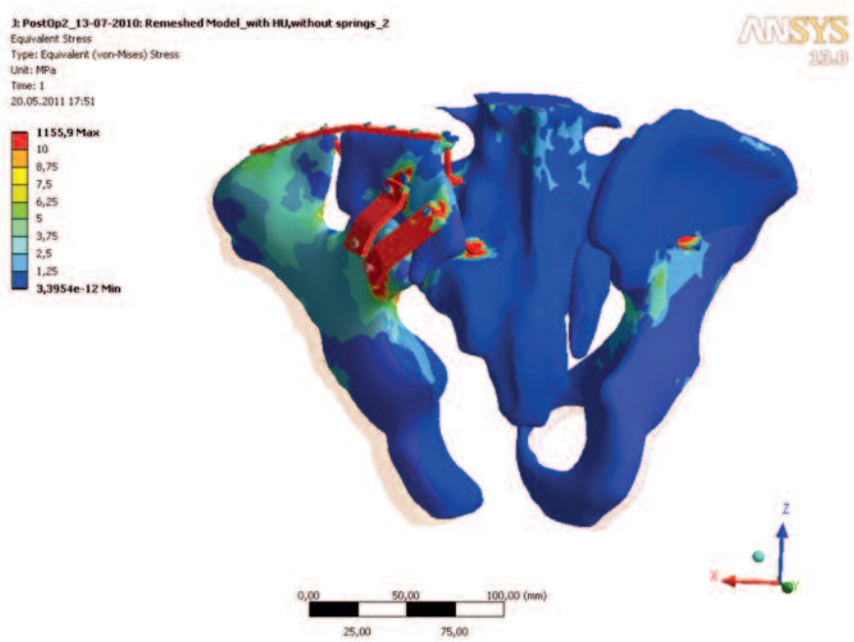
Der diesjährige Best Paper Award ging an Dipl.-Ing. Andreas Wittek (Goethe University Frankfurt/M) und seine Co-Autoren (Philipps University Marburg). Der Titel der Präsentation lautete „A Finite Element Updating method for in vivo identification of elastic properties of the human aortic wall based on full field displacement measurement by 3D ultrasound speckle tracking“.

Dipl.-Phys. Jürgen Salk (rechts) gratuliert Dipl.-Ing. Andreas Wittek (links) zum CBU 2013 Best Paper Award

Weitere Informationen finden Sie unter www.uni-ulm.de/misc/cbu.html

„3. came-Konferenz – Simulation in Medizin und Biomechanik“ fand in Mannheim statt

Am 20. Juni 2013 fand in Mannheim die „3. **came**-Konferenz – Simulation in Medizin und Biomechanik“ statt. Wie schon die Jahre zuvor wurde die **came**-Konferenz im Rahmen des ANSYS CADFEM Users‘ Meeting abgehalten, das mit über 900 Teilnehmern eine der größten Konferenzen im Bereich der numerischen Simulation ist. Die über 50 Teilnehmer der **came**-Konferenz aus Industrie, Gesundheitswesen und Wissenschaft konnten sich in 14 je 30-minütigen Präsentationen über praxisnahe Anwendungen der CAE-Simulation für medizinische Anwendungen und in weiteren Vorträgen zu technischen Grundlagen informieren. Die Vortragenden waren sowohl Ärzte als auch Ingenieure. Der Schwerpunkt der Vorträge lag dabei auf der Mund-, Kiefer- und Gesichtschirurgie, der Plastischen Chirurgie, der Orthopädie und der Bildgebung.



Die **came**-Konferenz wird von der CADFEM (GmbH) gemeinsamt mit der Forschungsgruppe CAPS – Computer Aided Plastic Surgery am Klinikum rechts der Isar der TU München und Dr. med. Dr. med. dent. Lars Bonitz vom Klinikum Dortmund organisiert.

Weitere Informationen zum Vortragsprogramm finden Sie unter www.cadfem-medical.com.

came-Board stellt caMe-Initiative erstmals auf „Internationalen CAE-Conference“ vor

Im Rahmen der TechNet-Alliance AG, einem internationalen Netzwerk von Firmen aus dem CAE-Bereich, wurde eine **came**-Initiative gestartet, die von den Mitgliedern des **came**-Board gesteuert wird. Die **came**-Initiative wurde dazu erstmals einer größeren Öffentlichkeit auf der „Internationalen CAE-Conference“ vorgestellt, die am 21. und 22.10.2013 in Lazise stattfand. Ziel der **came**-Initiative ist die langfristige Etablierung der CAE-Technologien und -Methoden in medizinischen Anwendungen. Dort sollen sie helfen, Operationen im Vorab am Computer zu planen und damit zu verbessern. Gemeinsam mit Ärzten und Ingenieuren werden geeignete medizinische Fragestellungen identifiziert, bei denen die Simulation einen Mehrwert für Arzt und Patienten verspricht. Auf Basis bestehender CAE-Programme sollen dann entsprechende Automatismen programmiert werden, um die erforderlichen Simulationen möglichst einfach durchführen zu können. Die Inhalte und Ausrichtung der **came**-Initiative wird vom dazu eigens gebildeten **came**-Board gesteuert.

Das **came**-Board geht auf die Empfehlung von Prof. Josten (Uniklinikum Leipzig) zurück. Neben den Ingenieuren sollen dort mittelfristig Ärzte aus allen relevanten Fachrichtungen vertreten sein. Zum jetzigen Zeitpunkt zählen zum **came**-Board: Dr. med. Dr. med. dent. Lars Bonitz (Mund-, Kiefer- und Gesichtschirurgie, Klinikum Dortmund gGmbH), PD Dr. med. Laszlo Kovacs (Klinik und Poliklinik für Plastische Chirurgie und Handchirurgie, Klinikum rechts der Isar, TU München), OA Dr. med. Jörg Böhme (Klinik und Poliklinik für Unfall-, Wiederherstellungs- und Plastische Chirurgie, Universitätsklinikum Leipzig), Prof. Brawanski (Klinik und Poliklinik für Neurochirurgie, Uniklinikum Regensburg), Dr. med. dent. Björn Ludwig (Kieferorthopädie, Traben-Trarbach). Aus dem Bereich des Ingenieurwesens sind Christoph Müller (CADFEM) und Bernhard Buchmeier (TÜV Süd) zu nennen.

*Wenn Sie Interesse an den Aktivitäten der **came**-Initiative haben, melden Sie sich bei Christoph Müller cmueller@cadfem.de.*

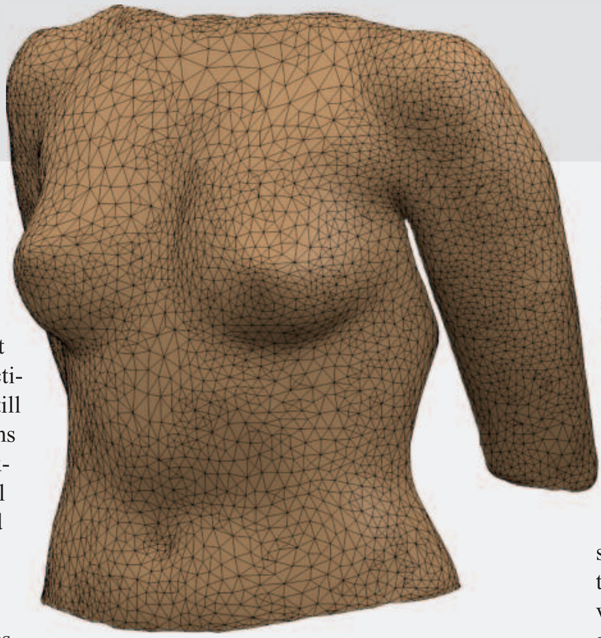
Gruppe CAPS erhält „Best Paper Award“ bei internationaler Konferenz

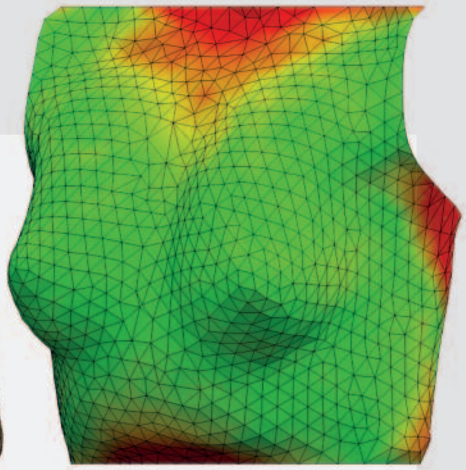
Ein Vortrag der Forschungsgruppe CAPS ist auf der internationalen Simulationskonferenz NAFEMS World Congress 2013, der vom 9. bis 12. Juni in Salzburg stattfand, ausgezeichnet worden. Die Gruppe erhielt den Preis für den innovativsten Einsatz von Simulationstechnologie (Best Paper Award in der Kategorie Most Innovative Use of Simulation Technology). Der Beitrag mit dem Titel „Parameter Identification for the Hyper-Elastic Material Modelling of Constitutive Behaviour of the Female Breast’s Soft Tissues Based on MRI Data, 3D Surface Scanning and Finite Element Simulation“ von den Autoren Stefan Raith, Max Eder, Alexander Volf, Jalil Jalali und Laslzo Kovacs beschäftigt sich mit der bildgestützen Erfassung von mechanischen Materialparametern des weibliche Brustgewebes und stellt damit ein Paradebeispiel für den interdisziplinären Ansatz der Gruppe dar.

Weiter Informationen unter www.caps.me.tum.de.

FEM-Simulation of the soft tissue of the female breast

S. Raith, M. Eder, J. Jalali, A. Volf, L. Kovacs*





Abstract

Today an objective planning tool for complex surgical interventions on the female breast, such as breast reduction or breast reconstruction after tumour resection is still missing. Instead, the physicians have to rely solely on their experiences and their individual skills. Modern software based planning tools that take advantage of numerical simulations which are widely used in today's engineering sciences have not yet found their way to the operating room. However we think that there is a remarkable potential for these computational methods to improve surgery planning.

Different modelling approaches have been proposed in literature to transfer medical imaging data to geometrical models of the female breast. However, the level of detail which is necessary for a sufficiently accurate operation planning simulation remains an open question so far. In this paper we investigate the influence of modelling detail on the behaviour of soft tissue deformation of the female breast due to gravity. In particular we are focusing on the modelling of the clavicular bone. A combination of magnetic resonance imaging (MRI) and three-dimensional body scanning (3D) together with finite element (FE) simulations is used to address this task. In the present study, two different geometrical modelling variants (with and without the clavicle bone) are derived from MRI data acquired from six healthy volunteers, lying in prone position. With the aid of the FE software package ANSYS a force free reference state is calculated out of these geometries, using an iterative heuristic approach to overcome the initial deformations caused by unavoidable gravity. Starting from the obtained approximation of the gravity-free state, the shape of the breast in standing upright position is calculated. The obtained result is then validated by comparison to the real volunteers' breast surfaces acquired with a 3D surface scanner.

It could be shown, that the influence of clavicular bone modelling has no statistically significant impact on the accuracy of these simulations. Hence, we conclude that there is no distinct need to consider the clavicle bones in this type of simulation. The increase in level of detail should rather be focused on the soft tissue compartments e.g. by the distinct differentiation between adipose tissue, glandular tissue, and muscles.

Keywords

plastic surgery, segmentation, magnetic resonance imaging, 3D surface scanning, breast, soft tissue deformation, finite element analysis

Kurzfassung

Verfahren zur objektiven Planung von komplexen chirurgischen Eingriffen an der weiblichen Brust, wie Brustreduktionen oder Brustrekonstruktionen nach Tumorentfernungen, sind heute immer noch nicht im klinischen Alltag etabliert. Stattdessen müssen sich die Ärzte einzig auf ihren Erfahrungsschatz und ihre individuellen Fähigkeiten verlassen. Moderne Softwareanwendungen, wie sie in den Ingenieurwissenschaften nicht mehr wegzudenken sind, könnten allerdings enormes Potential auch für Anwendungen in der plastischen Chirurgie haben.

In der einschlägigen Literatur sind unterschiedlich detaillierte geometrische Modellierungen für die Anatomie der weiblichen Brust vorgeschlagen worden. Der notwendige Detaillierungsgrad dieser Modelle ist heute noch nicht hinreichend bekannt. In der vorgestellten Studie untersuchen wir daher den Einfluss der Modellierung des Schlüsselbeines auf die Deformation des Weichgewebes der Brust. Eine Kombination aus Magnetresonanztomographie (MRT) und dreidimensionalen Oberflächenaufnahmen zusammen mit Finite-Elemente-Simulationen wird verwendet, um diese Aufgabe zu lösen.

Dazu wurden zwei unterschiedliche Varianten der Modellierung (mit und ohne Schlüsselbein) aus in Bauchlage aufgenommenen Volumenbilddaten von sechs gesunden Probanden erstellt. Mit Hilfe der Simulationssoftware ANSYS wurden mittels eines iterativen heuristischen Verfahrens Abschätzungen der spannungsfreien Form der Brust berechnet um die ursprüngliche Verformung der Brust durch Gravita-

tion zu überwinden. Ausgehend von diesen Abschätzungen lässt sich die Form der Brust in stehender Position berechnen, die dann zur Validierung der Simulation mit realen 3D-Oberflächen-Scans verglichen werden kann.

In dieser Studie konnte gezeigt werden, dass die Modellierung des Schlüsselbeines keinen signifikanten Einfluss auf die Genauigkeit dieser Simulationen hat. Daraus lässt sich folgern, dass keine explizite Notwendigkeit besteht, diese Knochen in solchen Simulationen zu modellieren. Stattdessen sollte eine Verfeinerung eher auf eine genauere Beschreibung des Weichteilverhaltens des Brustgewebes fokussiert sein.

Schlüsselwörter

Plastische Chirurgie, Segmentierung, Magnetresonanztomographie, 3D-Oberflächen-Scan, Brust, Weichteildeformierung, Finite-Elemente-Simulation

1 Introduction

Today an objective planning tool for complex surgical interventions on the female breast, such as asymmetry corrections, breast reduction or breast reconstruction after tumor surgery is still missing. Instead, the physicians have to rely solely on their experience acquired in previous procedures and their individual skills. Modern, software based planning tools that take advantage of numerical simulations which are today widely used in engineering sciences have not yet found their way to the operating room. However we think that there is a remarkable potential for these computational methods to improve surgery planning especially focusing on soft tissue surgery of the breast.

For sufficiently accurate planning of breast surgeries it is essential to find the right degree of abstraction. Thus it is an open question what anatomical details should be modeled and what parts can be neglected without making an unacceptable error.

Numerous academic studies have been performed where computer simulation approaches are used to describe the soft tissue deformation of the breast. These can be divided into different scopes, where consequently different boundary conditions and system boundaries are chosen to limit the simulation model in space. When it comes to deformations caused by mammography plates in breast cancer screening [1, 2, 3], these deformations are limited to a relatively small region. Hence, it seems justified to use a small simulation scope as well. In contrast when soft tissue deformations due to gravity effects are taken into account a simple definition of small system boundaries is not that easily applicable anymore. There are numerous studies that deal with gravity effects on the breast [4, 5, 6, 7, 8]. The authors of these publications limit the system space either to one isolated breast that is observed [4, 5, 8] or a relatively small axial slice containing the breasts is taken as a basis for the finite element meshing [6, 7].

The purpose of this paper is to investigate to what extent these assumptions are justified and whether there is any need to take more anatomy into account. To address this question, two different modeling variants are investigated: the first one where the clavicular bones are present in the simulation as fixed boundaries and an alternative configuration where these bones are completely omitted.

Both simulation models are created via manual segmentation out of magnetic resonance imaging (MRI) data that is transferred into volumetric finite element meshes. The initial imaging data was acquired in prone position thus the breasts are deformed by gravity loading. With the aid of the FEA software package ANSYS® a force free reference state is calculated out of these geometries, using an iterative heuristic approach to overcome the initial deformations caused by unavoidable gravity. Starting from the obtained approximation of the gravity-free state, the shape of the breast in standing upright position is calculated. The obtained result is then compared to the real volunteers' breast surfaces acquired with a 3D surface scanner in order to quantify how suitable the corresponding boundary condition variant is to describe the biomechanical behavior of the breast.

2 Material and Methods

In the study presented here, we utilize magnetic resonance imaging (MRI) data of the chest region of six healthy volunteers. The volumetric MRI-data was segmented into different anatomical compartments and finite element models were derived out of this data. Furthermore 3D surface scans of the patients were taken in upright standing position.

The imaging in upright position was performed using a surface scanner working with laser triangulation (Konica Minolta Co., Ltd., Osaka, Japan). This system has often shown its applicability to breast shape measurements in preliminary studies [9, 10, 11, 12, 13, 14]. The 3D surface scans of the subjects were performed in standing position on predefined markers on the ground under standardized lighting conditions with the scanner facing the participants in +30, 0 and -30 degrees relative to the lens in standing position [14]. During acquisition the females were asked to hold their breath. The arms had to be put down the side at the height of the pelvis and the back was supported by a wall to guarantee reproducible data by minimizing potential artifacts due to movements.

Volunteers with any known history of breast cancer, acute breast infections, severe breast malformations, thoracic deformations or previous breast surgeries were excluded from the study. No indications of existing breast asymmetries were observed and none of the volunteers did undergo any past surgical interventions in the breast area nor did they plan to do so in the future.

2.1 Volumetric Image Acquisition Segmentation of anatomical compartments

Volumetric Magnetic Resonance Imaging (MRI) data of the six volunteer was captured with the aid of a Philips Achieva 1.5 Tesla MRI scanner (Philips Medical Systems DMC GmbH, Hamburg, Germany), using a T1-weitghted imaging sequence with a 512 x 512 x 179 voxel resolution and a spacing of 0.994 mm x 0.994 mm x 2 mm (imaging parameter: 4.6 ms ecco time and 9.2 ms repetition time). No intravenous contrast medium was applied. The thoracic images were obtained with the participants lying in prone position. It was taken care that the breasts did not touch

*

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the MRI bench, which was achieved with pillows supporting the body at the clavicle, neck and shoulder region as well as further down to the lower belly area and the pelvic crest region. With this support structure, all compressions of the breast due to contact with the bench could be omitted. However the breast soft tissue is not undeformed because gravity forces still act and cause a non-negligible deformation of the breast. An axial slide of such acquired image data can be seen in *Figure 1*. Thus only the shape of the free hanging breast can be made available for further processing and segmentation in suitable imaging software packages. The resultant models can finally be used for finite element simulations.

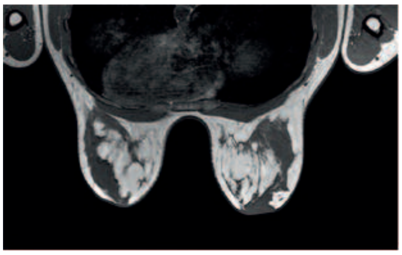

Figure 1: *MRI Images of the breast in prone position. Different anatomical compartments, such as adipose and glandular tissues of the breast can be captured due to differences in grayvalues.*

For the generation of individual specific volumetric simulation models, the underlying data for each FE model is reconstructed from the acquired MRI scans of the six participants. The images were saved in DICOM format and loaded into the Mimics® 14.0 software (Materialise Inc., Leuven, Belgium), where the different anatomical regions of interest were manually segmented and triangulated to divide the different anatomical compartments.

The anatomical regions that are considered to be relevant for the mechanical simulation in the presented study are limited to a simplistic modeling of only two different soft tissue compartments. The first one describes the adipose and glandular tissue summarized as one homogeneous part. The second tissue part that is segmented as volume compartment in these simulations is the muscular tissue.

As a posterior demarcation of the simulation model, the thoracic wall was modeled as a continued surface thus the intercostal muscles were considered to be one part together with the ribs and the breast bone.

For the modeling of the other potentially relevant bony part, two different variations of segmentation were created:

A. The first variant uses segmentations, where the clavicular bones are present. Those are in this assumption considered to be rigidly fixed similar to the thoracic wall and the lateral system boundaries.

B. In the alternative configuration both clavicular bones are completely omitted. In this variant the only segmented bony part is the thoracic wall, while the region of the clavicular bones is in this model meshed with elements that have soft tissue material properties assigned. Both variants are visualized in *Figure 2*.

The focus of this particular study is on the influence of clavicle segmentation, hence the material modeling is not the primary issue and we decided to use a distinct value that has proven its applicability in previous work (a Young's modulus of 0.78 kPa and a Poisson's ratio of 0.5, leading to incompressible material behavior). In the study presented here the muscle tissue was modeled with twice the stiffness of the adipose tissue and incompressible behavior as well. All utilized tissues are considered to be homogeneous and isotropic and as theoretic material model the Neo-Hookean model was chosen. The stiffness of bone tissue is several magnitudes higher than that of both adipose and muscular tissue and hence it can be considered to be rigid within the scope of our study. The skin is not considered as a separate part in this modeling.

All segmented surfaces were processed in adequate 3D surface processing software packages (Geomagic Studio 12®, Raindrop Geomagic, Inc., NC, USA and Blender®, Blender Foundation, Amsterdam, Netherlands) to improve the surface quality and reduce segmentation artifacts that could disturb later mesh generation. Triangulated surfaces prepared in this manner can be utilized for the division of the complex anatomical shapes into volumetric tetrahedron meshes. For the generation of the FE model the meshing software ICEM® (ANSYS Inc. Canonsburg, PA, USA) has been applied. In order to eliminate the irrelevant parts of the breast model for the FE simulations (like the shoulders), a box was defined to limit the model towards all sides. For the simulation, tetrahedron solid elements were used with u-p mixed formulation. This theoretical element formulation is suitable for general material formulations including incompressible materials, due to a hydrostatic pressure calculation. The group of non-clavicular segmentations had a node count of 4809.83 ± 447.86 while the group of clavicular segmentation models had 5033.16 ± 376.84. Thus there are significantly more finite element nodes necessary for the detailed modeling of the clavicular bone ($p < 0.05$). The programming language APDL (ANSYS Parametric Design Language) was used for implementation and automatizing the whole process.

As boundary conditions the system limits as described above, represented by the demarcation box have to be clearly defined in a standardized way to permit reproducibility. These system boundaries (as shown in *Figure 2*) on the upper and lower boundaries, as well as at the lateral and dorsal delimitations have been considered to be fixed boundaries, i.e. all finite element nodes at these locations are kept in place. The same is true for the thoracic wall in both variants and the clavicular bones in modeling variant A. As load case isolated gravity loading was chosen, similar to previously presented approaches [15, 16, 17]. Comparisons between the two modeling variations were performed with Student's t-test for paired samples and a value 0.05 was defined to be the threshold of significance.

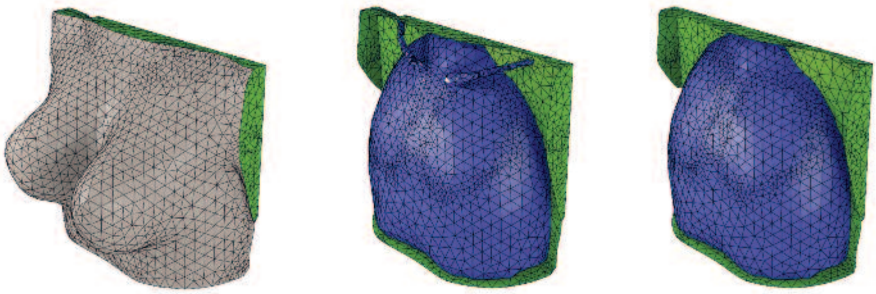

Figure 2: *Meshing of the breast anatomy. Left: whole body model meshed with tetrahedrons, middle: fixed boundaries for the model with clavicles, right: fixed boundaries for the model without clavicles. The system boundaries are shown in green.*

2.2 Finite element analysis and iterative procedure

As previously mentioned the starting configurations of the models that are based on MRI images taken in prone positions may not directly be used for finite element simulations because of the unknown initial deformation due to gravity. Due to the soft constitution of the tissue, the breast is highly deformed even if besides gravity no other forces are acting. But for mechanical simulations, an unloaded state of the geometries has to be known to be used as the starting geometry by the simulation. Calculating the non deformed reference state out of a known deformed configuration can be classified as an inverse problem. Due to the high deformation and the hyperelastic material behavior, a simple, one-step inverse calculation with inversed gravity loading is not satisfyingly accurate. Some previous studies did not consider these effects and used a single step method instead [7]. But recently, more advanced investigations on this subject have been conducted taking into account these influences [8, 5]. Rajagopal et al. presented an inverse algorithm for breast soft tissue simulation to deal with this topic.

To address this issue in this work, a similar algorithm has been developed in ANSYS APDL that is capable of calculating a stress free representative of the model based on a geometry which has been acquired under gravitational loading. The principle workflow of the method is shown in *Figure 3*.

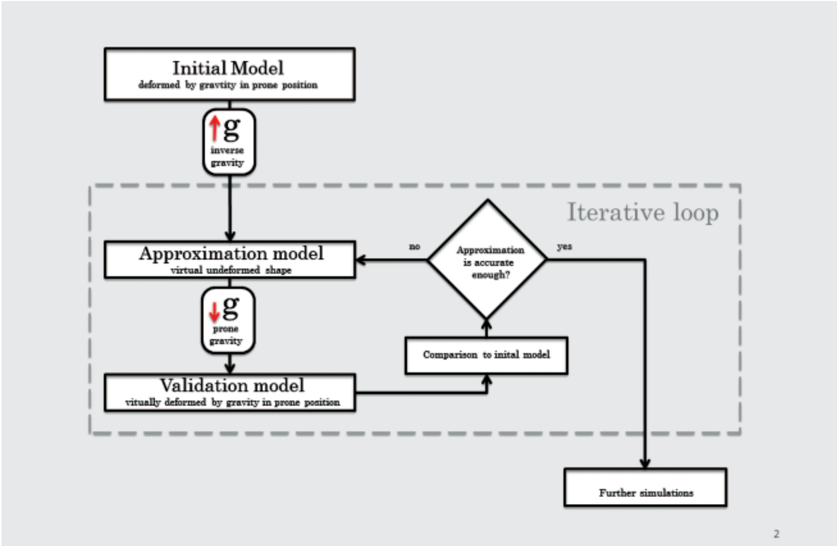

Figure 3: *Principle sketch of the iterative procedure for the approximation of the load free configuration.*

The initial configuration is the gravity deformed model segmented form MRI data (shown in *Figure 4*, top row left). A first approximation of the non-deformed configuration is made by a one-step backward calculation with inverse gravity (the result can be seen in *Figure 4*, top row middle). The obtained result is then taken as the starting point to perform a forward calculation, while it is again considered to be stress free initially. In this calculation step the gravity is pointing in prone position again to simulate exactly the position that was initially acquired from the MRI data (see *Figure 4*, top row right). For verification, it is now possible to check the error of the first inverse calculation by comparing the new result (*Figure 4*, red) with the initial geometry that is deformed by gravity (*Figure 4*, green). Because the meshing of the model does not change throughout the

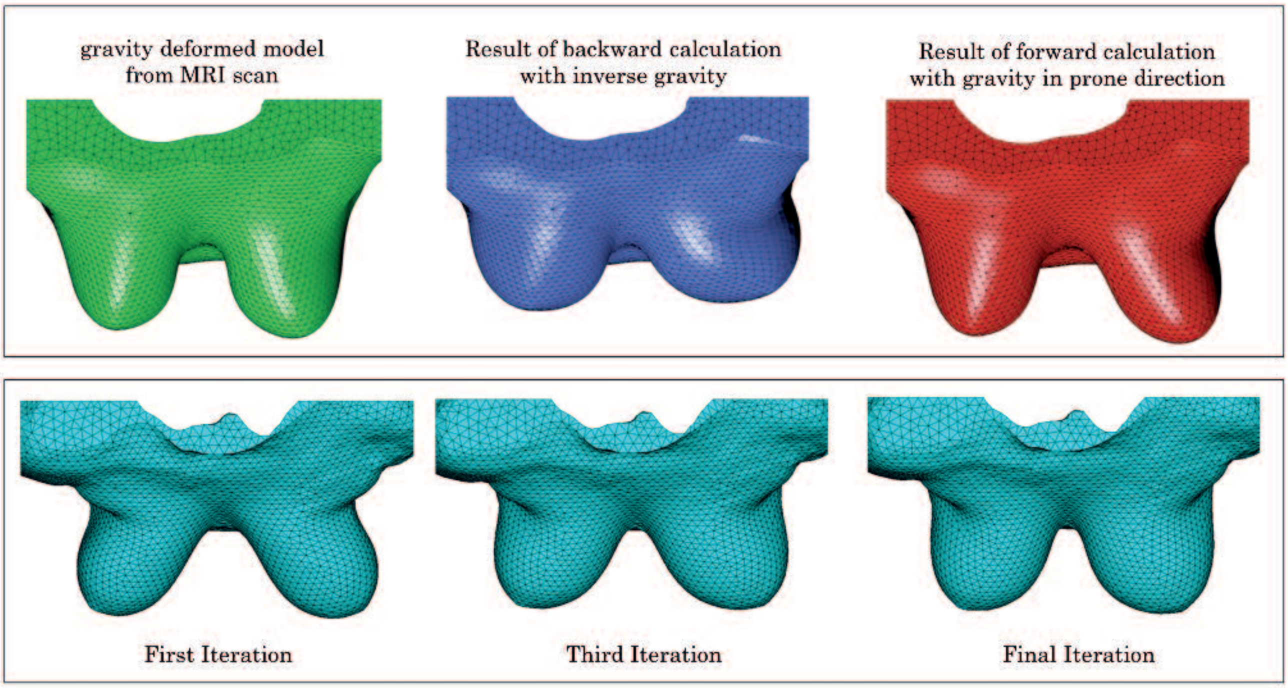

Figure 4: *Top row: left: initial model segmented from MRI data with deformations due to gravity in prone position. Middle: results of a single step backward calculation; right: result of a forward calculation with gravity in prone position. Bottom row: first, third and final (in this example 11th) step of the iterative procedure. Lateralization of the breast is constantly decreasing with more simulations.*

simulation steps, the positions of all nodes can be compared directly. The differences of these two models are used to make a better estimation of the unloaded configurations by taking these nodal deviations into account for a better approximation of the unloaded configuration. Thereby, a better estimate may be achieved, which can be used again as an unloaded configuration for a new forward calculation. Thus a loop as visualized in *Figure 3* is developed, because the newly calculated deformed position can be compared again to the segmented positions from MRI data and subsequently the comparison result can be used to further improve the estimate of the unloaded configuration. The loop may be performed until a certain threshold for accuracy is passed or a maximum number of iterations is reached. In the present study a maximal repetition of 5 iterations was indicated. In *Figure 4* (bottom row) different stages of the iterative procedure are shown. In the first approximation the breasts are obviously lateralized. Subsequent calculations are improving the approximation of the unloaded configuration leading stepwise to better results in accordance between forward calculation results and the initially available gravity deformed model from MRI data.

When a sufficiently accurate approximation of the undeformed model is reached, this mesh is used to be the starting model for a calculation of the standing configuration. For the purpose of validation the FEA result of this final calculation is compared to the 3D surface scan that is available as well. For this task only the skin surface part of the volumetric tetrahedron elements is utilized. For the 3D comparisons a specially developed algorithm has been used that calculates the node to node root mean square integration, according to the method described in [18]. *Figure 5* shows a color visualization of a comparison between finite element result and 3D surface scan. The whole workflow is automated and may be used in batch mode to allow fast processing of data with minimal efforts.

3 Results

The comparison between simulation results and 3D surface scans in standing position is visualized for an example data set in *Figure 5*. The color scale on the simulation model shows the 3D differences between the two geometries. Especially in the shoulder region there is a high deviation resulting from different movements of the arms between the two utilized imaging modalities. These effects cannot be dealt with in this scope of simulations. However considering the breast as the main area of interest in this study the deviations remain within a tolerable range. This finding has been true for all subjects included in this particular study and for both modeling variations. Thus, the applicability of the presented workflow for the simulation of the breast could be shown. The whole process is automated and thus permits an easy to use interface for the comparison of different geometrical models and different boundary conditions.

Comparing the calculation times for both modeling variants, the group A (with the clavicle bones) showed an average time of 5.09 ± 2.34 min while the calculation times of group B (without clavicles) resulted in 4.25 ± 2.02 min. The advantage of group B regarding the computational effort is not surprising, when taking into account the above mentioned significantly lower node count in the meshing stage. However, this difference in calculation times is not significant ($p > 0.05$). An expansion of subject number that increases the statistical power of the comparison might clarify if this effect truly exists.

In *Figure 6* the integrated mean 3D surface distances between the two groups are visualized for each volunteer. For all models the results with the chosen material properties are in comparable magnitudes ranging from 7.26 mm to 12.57 mm. There is no strong difference between the two modeling groups in none of the test subjects to be recognized. In five out of the six tested models, group A was superior compared to group B. However all differences are small (with a maximum advantage for group A of 4.8 % in subject 2). Model 3 showed an advantage of 1.69 % for group A but a slight advantage for group B of

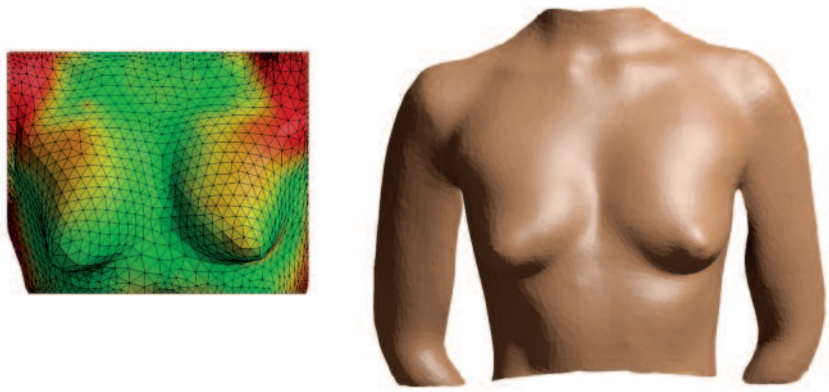

Figure 5: *Typical simulation result (left) in comparison to the 3D surface scan acquired in standing position (right). The surface deviations correlate to the coloring of the simulation model.*

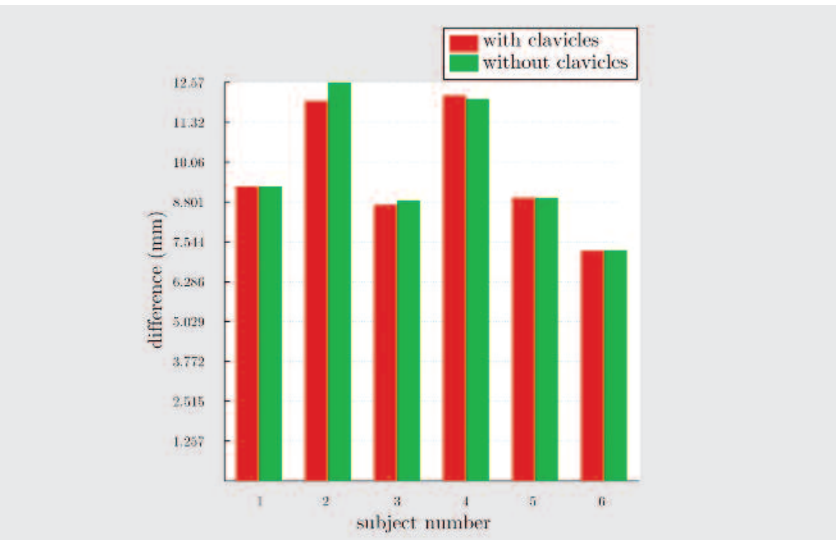

Figure 6: *Bar diagram showing the integrated mean difference between simulation results and 3D surface scans in standing position for the models with clavicles (red) and the models without (green).*

0.85 % for model 4. For three subjects (1, 5 and 6) diminutive differences could be found (0.05 %, 0.05 % and 0.27 % respectively). Taking all subjects into account, no statistically significant difference between the two alternative modeling approaches could be investigated (p = 0.32).

4 Discussion

Based on the study's outcome that no statistically significant differences between the two modeling variations with or without clavicular bone could be investigated, we can conclude that it is not important whether these bones are modeled in the simulation or omitted. Considering the tedious segmentation process and the increase in simulation model size which is a result of the relatively fine mesh that has to be used to include the clavicular bone in the simulation are drawbacks of the variant with clavicular bone. Hence, we conclude that there is no distinct need to consider the clavicle bones in the type of simulation of the breast's soft tissue movement that has been performed in this work.

However, when other body movement should be simulated, the clavicle segmentation may be inevitable. For example it is essential for the simulations of arm movements and the resulting deformation of the soft tissue parts of the shoulder areas and may then also have considerable effect on the deformation of the breast. This movement is necessary to provide sufficiently accurate simulations of the deformation of the breast during intraoperative repositioning of the patient for example in tumor tracking.

The advantage of the whole workflow presented here is the non-invasive character as a combination of volume imaging (MRI) and 3D surface scanning (laser triangulation) and the involvement of the computer for the actual simulation. No tissue samples of the patient's soft tissue have to be harvested what is especially a crucial issue if the mechanical information derived from these specimens should be used in operation planning, because this would mean an additional intervention for the patients. Furthermore, the expensive and cumbersome experimental testing can be circumvented. Since the whole workflow of simulation and data evaluation is automated, multitudes of simulations can be performed with few additional effort. This makes e.g. variations in material parameters possible as shown in previous works [15, 16, 17].

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Short Biography

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Veranstaltungen

20. bis 25. Juli 2014 in Barcelona

Minisymposium: Computational Methods for Artificial Organ Development

The 11th. World Congress on Computational Mechanics (WCCM XI), 5th. European Conference on Computational Mechanics (ECCM V) and 6th. European Conference on Computational Fluid Dynamics (ECFD VI) will to be held in Barcelona on July 20 - 25, 2014.

The Department of Cardiovascular Engineering (Helmholtz Institute, RWTH Aachen University) is organizing the Minisymposia Computational Methods for Artificial Organ Development. This Minisymposium aims to foster a detailed discussion on the use of computational methods during artificial organ development as well as experimental and clinical validation thereof. Applications of computational mechanics, computational fluid dynamics, coupling mechanisms and further modelling techniques are discussed in the framework of artificial heart valves, stents, blood pumps, oxygenators, dialyzers and other artificial organs. The goal is to optimize designs with respect to efficiency, durability and hemodynamic requirements. Besides computational modelling linked directly to artificial organs themselves, special focus lies on the interaction of these devices with the human body.

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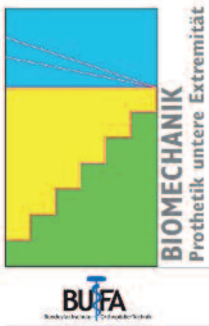
30. Juni bis 1. Juli 2014 in Dortmund

Seminar der Bundesfachschule für Orthopädie-Technik: Biomechanik-Prothetik untere Extremität



Physik und Biologie sind die Grundlagenwissenschaften der Orthopädie und der orthopädischen Chirurgie. Die Erkenntnisse aus der biomechanischen Forschung fließen in den praktischen Alltag der Hilfsmittelversorgung ein. Pathologische Haltungs- und Bewegungsmuster oder die Auswirkungen von Prothesen auf die Mobilität des Menschen sind nur erkennbar, wenn grundlegende Parameter erkannt und bekannt sind.

Mit dem Einzug mechatronisch gesteuerter Knie-Passteile erhielt die Prothesenversorgung eine neue Dimension. Umso wichtiger wird es, Biomechanik und Versorgungstechnik im Bereich der Prothesenversorgung zusammenzubringen. Darum geht es in diesem Seminar: Erkenntnisse aus der orthopädischen Biomechanik zu verstehen und für die Lösung praktischer Fragen in der Prothesenversorgung zu nutzen.

Der Schwerpunkt Prothesenversorgung der unteren Extremität wird durch Praxisdemonstrationen an Patienten mit Prothesen vertieft. Dieses Seminar kann im Rahmen der Genium-Zertifizierung der Firma Otto Bock zum Nachweis der Biomechanik-Kenntnisse anerkannt werden.

Bundesfachschule für Orthopädietechnik
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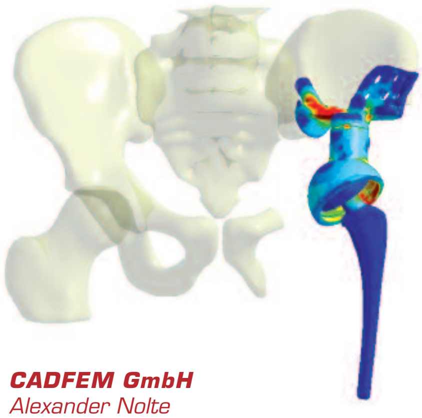
Seminar: Finite-Elemente-Simulation für Biomechaniker und Mediziner

Das Seminar führt in die Finite-Elemente-Methode (FEM) im Bereich der Biomechanik ein. Die Teilnehmer erarbeiten grundlegendes Wissen der Mechanik und üben seine Umsetzung. Darauf aufbauend lernen sie verschiedene Einsatzmöglichkeiten der FEM anhand einfacher medizinischer Fallstudien kennen. An einem konkreten Beispiel wird die Simulation geübt: Von der Erstellung eines FE-Netzes aus klinischen Bilddaten (CT, MRT) über die Materialmodellierung mit biologischem Gewebe bis hin zur Auswertung der Ergebnisse. Folgende Themen werden behandelt:

- Anschauliche Einführung in die FEM und wichtige mechanischen Grundbegriffe
- Planung und Aufbau einer FEM-Simulation
- Einführung in die Benutzeroberfläche von ANSYS Workbench
- Erstellung eines medizinischen FEM-Modelles
  - Erstellung eines FE-Netzes aus klinischen Bilddaten (CT, MRT)
  - Definition von Belastungen (Kräfte, Lagerungen)
  - Materialgesetze für biologische Gewebe (Knochen, Knorpel, Bindegewebe)
  - Modellierung von Kontakten (z.B. Gewebe-Implantat-Kontakt)
  - Auswertung von Ergebnissen (Verformungen, Dehnungen, Spannungen)
- Durchführung einer FEM-Simulation an einem Beispiel aus der medizinischen Anwendung

Für das Seminar werden keine FEM-Kenntnisse erwartet. Referenten sind Dr.-Ing. Ulrich Simon und Alexander Nolte, M.Eng.: Dr. Simon ist seit 2006 Geschäftsführer des Ulmer Zentrums für Wissenschaftliches Rechnen (UZWR) an der Universität Ulm. Seine Forschungsgebiete umfassen u.a. die Frakturheilung, muskuloskelettale Systeme, Knochen-Implantat-Kontakt und Knochenfestigkeit. Alexander Nolte arbeitet seit 2007 bei der CADFEM GmbH mit dem Schwerpunkt Biomechanik.



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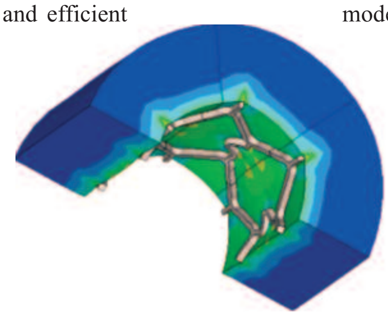

generation methodology is presented along with instruction in how to expand, crimp and simulate a variety of loading environments. Post processing of results is also covered - calculation of strains, radial stiffness, bending stiffness, shortening, fatigue life and other key measures of performance are computed. Elasto-plastic (for balloon expanded stents) and Shape Memory Alloy (for self expanding stents) material models are discussed along with appropriate contact algorithms. ANSYS software is used for this hands-on training. Notes and macros are provided to all attendees to take with them for further use.

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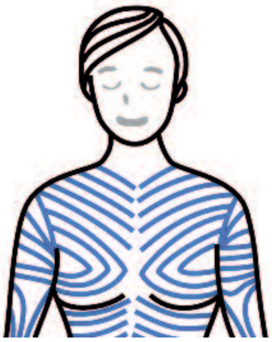
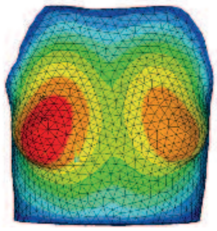
Vorschau

Heft 1 | Juni 2014

Modeling of Anisotropy Directions for Biomechanical Simulation of Human

The orientation of collagen fibers and their spatial distribution predefine macroscopic mechanical properties of the soft tissue and in particular its anisotropy directions. However, the definition of these directions in full body scale models is a challenging task. In the proposed approach, a vector field is calculated by the Laplacian smoothing method based on custom user defined sketches of fiber direction according to anatomical knowledge. The acquired result shows good agreement with the Langer's lines of the human skin. These resulting anisotropy directions are used as input data for mechanical simulations that consider the anisotropic properties of the skin with different theoretical material formulations.

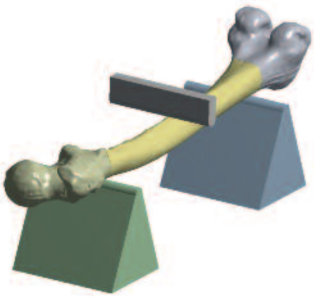


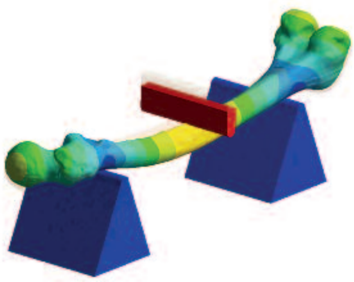


Computational Modeling: Comparison of femur bone stiffness using 3 point bending test

Bone is a connective tissue composed of compact (cortical) and trabecular (Spongy) bone. Result of the finite element simulations are greatly influenced by grid structure and material properties. However, the required sets elastic properties and mesh generation techniques for bone structures are still unclear.

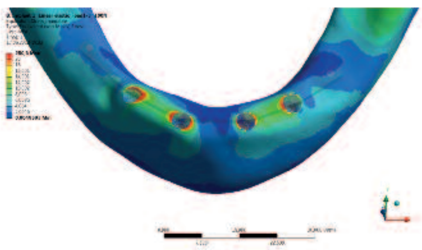
In this study three dimensional geometry of bone is reconstructed from CT scan data. Various methods of mesh generation and its effect on simulation results are presented.

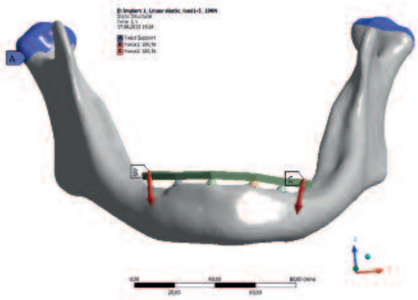




Spannungsverteilung im zahnlosen Unterkiefer bei unterschiedlicher Länge dentaler Implantate – Eine Analyse am Finite Elemente Modell

Gegenstand der Untersuchung ist die Spannungsverteilung bei unterschiedlich langen dentalen Implantaten unter simulierter funktioneller Kaubelastung am atrophen, zahnlosen Unterkiefer. Die Arbeit basiert auf der Analyse eines Finite-Elemente-Modells. Das zugrunde liegende Modell wurde aus einem speziell aufbereiteten CT-Datensatz eines zahnlosen, atrophen humanen Unterkiefers in Dünnschichttechnik generiert. Die Einleitung der Kaukräfte auf die dentalen Implantate bzw. deren Suprakonstruktion und die resultierende Spannungsverteilung im Implantat und im umgebenden Knochen wurden innerhalb der virtuellen Umgebung der Ansys-Workbench realisiert.





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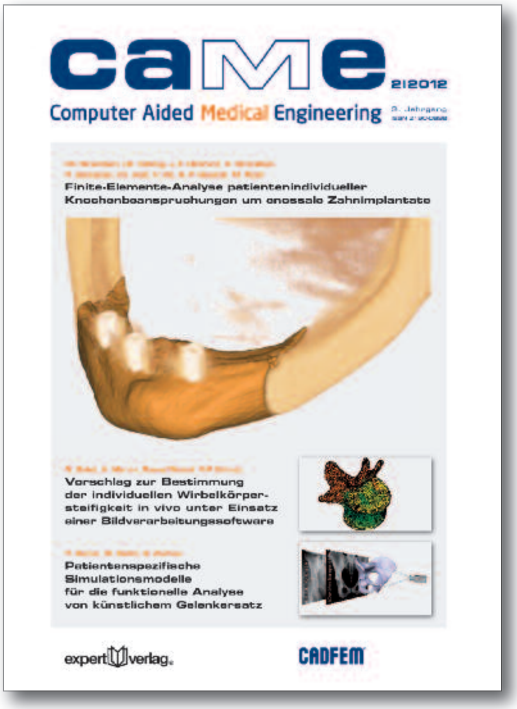

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- *Materialgesetze und Materialparameter für hartes und weiches Gewebe, z.B. Knochen, Fett- oder Muskelgewebe*
- *Design und Herstellung (Rapid Prototyping) von patienten-spezifischen Implantaten*
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