METHODOLOGY OF VIRTUAL COMPUTATIONAL MODELS SETUP

EXPERIMENTAL IDENTIFICATION OF BASIC MATERIAL PROPERTIES OF MUSCLE OF URETRINE WALL

F. Lopot*, P. Kubový*, K. Jelen*, V. Nováček**, Š. Budka***,A. Doležal****

* Charles University/Dep. of Anatomy and Biomechanics, Prague, Czech Republic
** University of West Bohemia/Department of Mechanics, Plzeň, Czech Republic
*** Gynecologic and obsterics clinic of 3rd FMCU and GTH, Prague, Czech Republic
**** Gynecologic and obsterics clinic of 1st FMCU and GTH, Prague, Czech Republic

flopot@seznam.cz

Abstract: Experimental identification of material properties of biological tissue will be presented by nondestructive tensile test of uterine wall muscle. The results will be used in virtual model of pregnant uterus in 8th month of gestation. For simulation of excessive loads, the maximal tensile strength has to be found. The tensile test will then be used again, but in this case destructive. The topic of this article is to describe used method of acquired data processing in case of nondestructive tensile test.

Introduction

Material characteristics of every single structure of computational model have important influence on its precision, with which it will reflect the reality. Material properties identification is usually done in vitro and thus it does not contain any information about physiological responses to external stimulations, e. g. muscle contraction after irritation. This imperfection does not seem to have an important influence on model precision mainly in case of fast excessive loads [7]. To ensure validity of all values the experiment should always be designed in such a way as to take into account final use of virtual computational model. It means that values of external quantities and other conditions of the experiment have to reflect values of external quantities and conditions in the simulation. From this point of view, the most important factors are loading time, intensity and history of load or deformation and temperature.

Materials and Methods

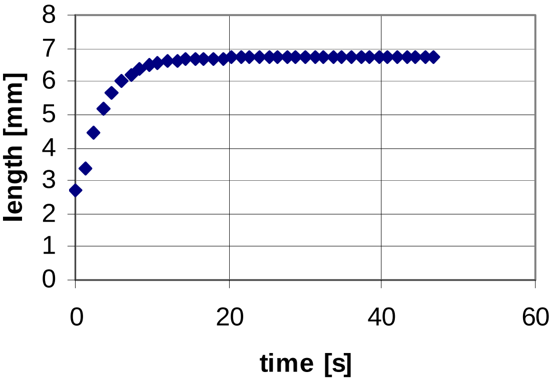
Sample description

The uretrine wall samples are taken during childbearings (caesarian section) or gynecological operations from bottom part of uterine corpus of healthy women of age from 21 to 50 years. Before testing, the samples are conserved in physiological solution at temperature from 5 to 6 °C not longer than 12 hours [2].

Testing method

Before testing, the dimensions of the samples are standardized to 5x2x10 mm with tolerance of ±1 mm. During testing the samples are not moistened.

For the tensile test special machine Perkin-Elmer DMA 7E is used. The force is the controlled variable. First the sample is exposed to several loading cycles with force from 0 to 2 mN to eliminate influence of irreversible changes in fortifying and viscosity elements [3]. After this stabilization the sample is loaded by a constant force and its length is measured.



ISSN: 1727-1983 © 2005 IFMBE

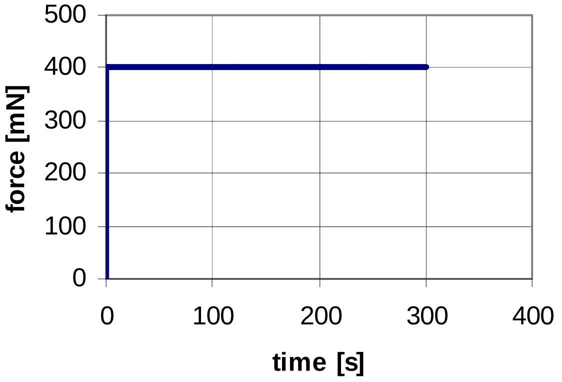


Figure 1: Loading force - step function

Figure 2: Sample response
Loading force characterization:

Force:	400 mN
Step function time:	300 s

Environmental conditions during the test were as follows: constant air moisture 68 % and temperature from 26,4 to 32 °C.

Data processing

The material is modeled as visco-elastic by a parallel junction of viscous and elastic elements.

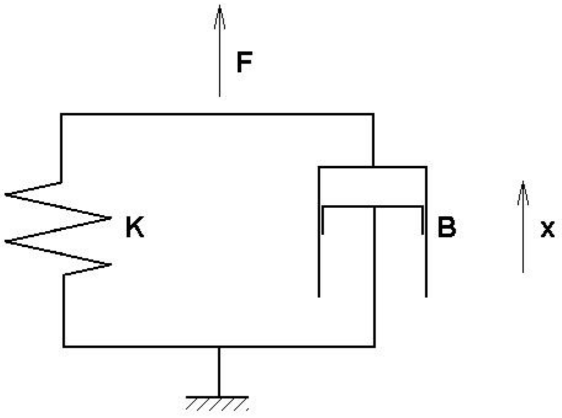


Figure 3: Material model

Neglecting inertial effects (e.g. sample mass) the model is described by the following formula:

$$F = K.x + B.\dot{x}\,, \qquad (1)$$

where ***K*** is strength of the elastic element and ***B*** denotes index of the viscous element. Both elements are considered linear. Time derivation is denoted by a dot above the symbol of the respective variable.

Definition of material creep:

$$\dot{F} = 0 \qquad (2)$$

Solution of the equation (1) is:

$$x = x_1 - (x_1 - x_0)e^{\delta.t}\,, \qquad (3)$$

where $\boldsymbol{x_0}$ is sample length at test start and $\boldsymbol{x_1}$ is asymptotic length of sample.

Analytic solution (3) is fitted to measured data and value of $\boldsymbol{\delta}$ is calculated by a suitable iteration method. Symbols x0 and $\boldsymbol{x_1}$ denote the measured values.

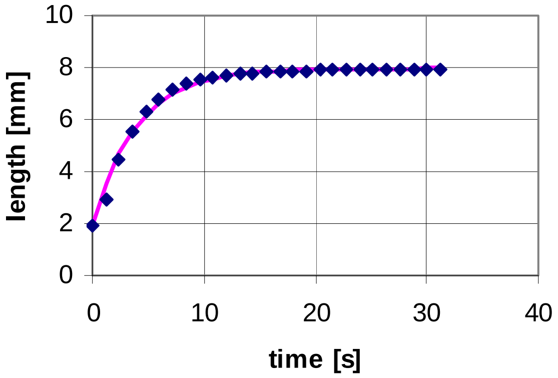


Figure 4: Acquired data and regression curve

The formula for $\boldsymbol{x_1}$:

$$x_1 = \frac{F}{K} \qquad (4)$$

can be rearranged to give:

$$K = \frac{F}{x_1} \qquad (5)$$

where ***K*** is strength of elastic element of the model.

The formula for $\boldsymbol{\delta}$:

$$\delta = -\frac{K}{B} \qquad (6)$$

Rearrangement of equation (6) yields:

$$B = -\frac{K}{\delta} \tag{7}$$

Substituting ***K*** value into the equation (7) the index of the viscous element of the model (***B***) is calculated.

Formula (4) determines length of the sample at infinite time. With regard to adaptability of biological materials to loading, this value is valid in reality only in a limited time interval.

Results

So far, 10 samples were tested. The first sample was used only for setup of the testing protocol and for finding of suitable values of the loading force. Nine samples were then exposed to the test procedure. In three cases, some errors were detected. Table 1 does not include measurement of the first sample and of those 3 erroneous tests either.

Table 1: Values ***K*** and ***B***

<table>
<tr><th rowspan="2">sample</th><th colspan="2">K</th><th>B</th></tr>
<tr><th colspan="2">mN/mm</th><th>mN/mm.s</th></tr>
<tr><td>1</td><td colspan="2">0,058</td><td>0,112</td></tr>
<tr><td>2</td><td colspan="2">0,056</td><td>0,106</td></tr>
<tr><td>3</td><td colspan="2">0,060</td><td>0,118</td></tr>
<tr><td>4</td><td colspan="2">0,057</td><td>0,118</td></tr>
<tr><td>5</td><td colspan="2">0,059</td><td>0,121</td></tr>
<tr><td>6</td><td colspan="2">0,057</td><td>0,120</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>arithmetic mean</td><td>K</td><td>0,0578</td><td>mN/mm</td></tr>
<tr><td></td><td>B</td><td>0,116</td><td>mN/mm.s</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td rowspan="2">max. deviation from the arithmetic mean</td><td>K</td><td>3,746</td><td>%</td></tr>
<tr><td>B</td><td>8,489</td><td>%</td></tr>
</table>

Discussion and conclusions

The results suggest that the selected structure of the model (see Figure 3) is appropriate.

There is a certain discrepancy between the fitted curve and measured values at the initial part of the sample response to loading suggesting existence of a small delay. This is still to be properly investigated, probably by means of a second order model. Also sampling frequency will have to be increased for this.

The study is going on with the aim to test altogether 50 samples or more. It is planned to include also several samples taken from uteri of diabetic women. To obtain more complete information on material characteristics (maximal tensile strength, see above) destructive tensile tests will be done, too.

Acknowledgements

This research is supported by projects SD 2333120024, SD 2333130003.

References

[1] Moorcroft, D., Stitzel, J., Duma, G., Duma, S.: Computational Modeling of a Pregnant Occupant. Virginia Tech, Center for Injury Biomechanics, 2001

[2] Yamada, H.: Strength of biological materials- edited by Evans. Wiliems & Wilkins Co., 1970

[3] Valenta, J., et al.: Biomechanika. Academia, 1985

[4] Pearlman, M., D., Ashton-Miller, J., A., Dyer, T., Reis, P.: Data acquisition for development to characterize the uteroplacental interface for the second-generation pregnant abdomen. NHTSA, 1999

[5] Oda, K.: Study on the bursting test of rabbits viscera and tissues. Med. Univ. Kyoto, 1952

[6] O'Hara, T.: On the comparison of strength of the various organ tissue. Med. Univ. Kyoto, 1953

[7] Gollnast, H., K., Dieminger, H., J.: Quantitative Bestimmung mechanischer Eigenschaften den graviden Uterus, Centralblatt für Gynaekologie, 1982

[8] Pearsall, G., W., Roberts, V., L.: Passive mechanical properties of uterine muscle (myometrium) tested in vitro. Journal of Biomechanics, vol. 11, 1978

INTERACTION BETWEEN SKI – SKIER MATHEMATIC MODEL OF LOADING ACL

J. Martiník, K. Jelen

Charles University/Dep. of Anatomy and Biomechanics/Lab. for extreme loading, José Mártího 31,
162 52, Prague 6, Czech Republic

info@feelnat.cz

Abstract: Mathematical model describing response of anterior cruciate ligament (ACL) to loading during skiing – its construction and possible benefits to prevention of ACL rupture (biomechanical view).

Introduction

Prevention and statistics of injuries has been very important to the European Union and based on its regulations, the situation has been monitored also in the Czech Republic since 2000 (performed by Research Institute for National Health, RINH). Statistical tables are led by head injuries while knee injuries are placed second (data of 2000). Knee injuries, especially ruptures of ACL during sport activities are the focus of our project. Injuries and overloading of ACL are very common in Alpine skiing. New technologies and contemporary construction of skis and ski boots helped to eliminate e.g. ankle injuries, on the contrary, the accident rate in the area of knee (especially ruptures of ACL) has been growing up. Ruptures of ACL make 20% of all ski injuries (in figures: Salzburg hospital for example cared for altogether 550 injured skiers during last season) (sporting activities cause 35% of knee injuries). Not all ACL ruptures come up with falls. Easy skiing with modern skis (a large side cut) brings extensive overloading of ACL and therefore higher possibility of knee injury. NACHBAUER and KAPS investigated loading on knees in different sports. They constructed a special plate for Alpine skiing. The plate was placed between ski and ski binding and it recorded value of impressive forces in 3D between the two of them. Mathematical processing of these data can provide us with values of impressive forces and moments on 3 axes in the area of ski binding. Team of Czech authors worked up the issue by focusing on both more effective wireless transmitting of the data from the measuring plate to computer and less expensive construction of the measuring device. Our task is to build the mathematical model of loading on ACL during skiing with use of studies by NACHBAUER 1996 and VODICKOVÁ 2003. In collaboration with the Technical University in Liberec, the above mentioned measuring plate will be used to obtain all necessary data. The measuring device contains twelve strain gauges with multi-channel data output. Computer no longer has to be attached to tester's back and is now placed in portable laboratory. The plate provides us with data from interaction on ski-ski binding interface, which can be used for calculation of impressive forces and moments in knee joint. Matrix and differential calculus will be used to obtain loading parameters of ACL during sporting activities. Technical solution of measuring 3D knee joint angle during skiing has to be found as these data are necessary for modeling of mechanical loading in knee joint. Our new laboratory BEL (Biomechanics of Extreme Loading, FPES, Charles University) has been currently testing another option of 3D motion analysis: QUALYSYS system with six high-speed cameras PROREFLEX 1000. After calibration of the area, this system enables to record any 3D motion. It is very important that the data from this system can be transmitted to VISUAL 3D (a program for processing of 3D motion data; the program has been also recently tested in BEL laboratory).

Materials and methods

Mechanical parameters of skis and skiing technique directly affect motoric apparatus of a skier. Maximum tolerance of motoric apparatus has to correspond to mechanical parameters of skis and skills of the skier so that this limit is not exceeded during their interaction. Our project focuses on overloading and rupture of ACL.

Methodology:

Four different methods are included in the project:
a) Cinematographic method for 3D motion analysis with the QUALISYS system (Biomechanics of Extreme Loading laboratory, FPES, Charles University)
b) MRI of knee and AMIRA – software for 3D geometric model
c) Calculation of impressive forces and moments in knee joint during skiing under real conditions with use of special devise developed at the Technical University in Liberec
d) Processing of measured data in VISUAL 3D (the program is able to work with all 3D motion data obtained by mentioned methods). Building the mathematical model of loading on ACL during skiing will be based on the finite element method.

ISSN: 1727-1983 © 2005 IFMBE

Measuring device:

a) The QUALISYS system used in BEL laboratory includes six high-speed cameras PROREFLEX 1000. These cameras are arranged into the shape of circle and the area is calibrated. Key spots of the investigated object are marked with special reflective Marker kits. The cameras scan only these kits, everything else can be therefore modeled and defined as needed. A selected motion can be subsequently studied on the monitor. This system can be synchronized with many other technologies such as KISTLER, FOOTSCAN, and so on.

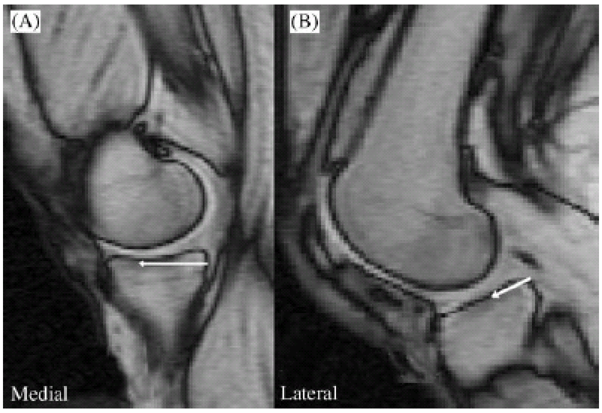


Figure 1: MRI of knee

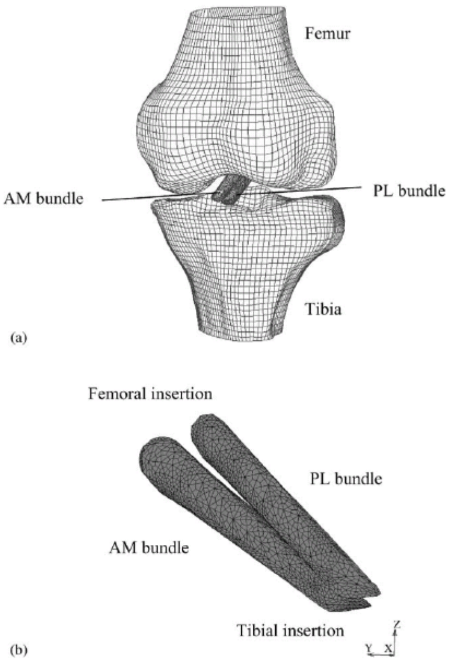


Figure2: 3-D FEM of the ACL for a human left knee:
(a) femur and tibia included in the model (anterior view),
(b) without femur and tibia included in the model (medial view).

b) MRI of knee, will be using for making virtual points in VISUAL 3D, exactly ACL and for synchronization data with AMIRA – software for 3D geometric model.

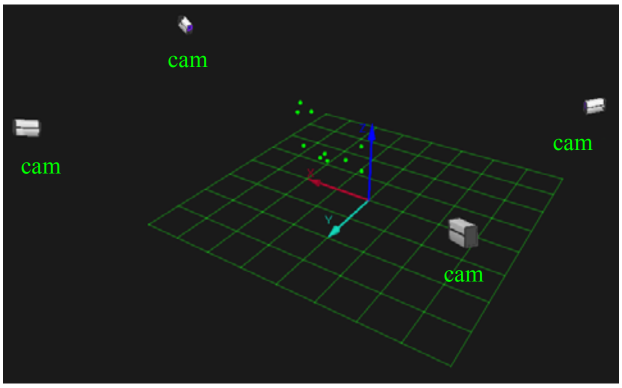


Figure 3: Record of QUALISYS track manager

c) Validity of data measured on ski-ski binding interface is essential for harmonization of theoretical and experimental part of the project. Data obtained from individual sensors in the measuring plate are reciprocally added and deducted. In laboratory could be used only Kistler plate (simulation of move, not real skiing)

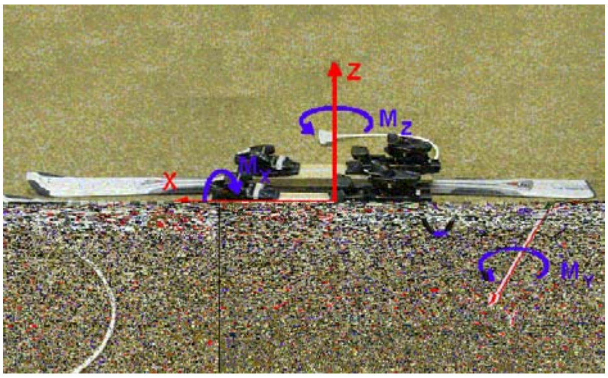


Figure4: Ski with measuring plate

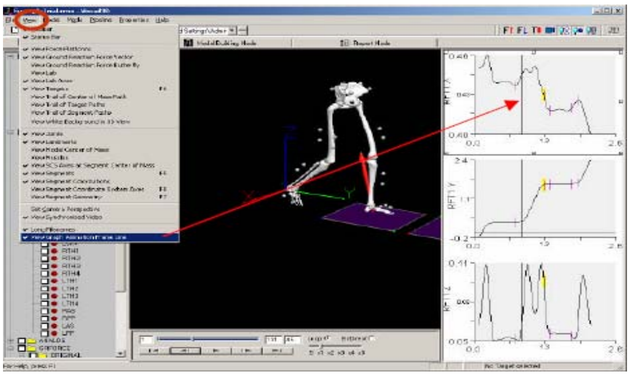


Figure 5: C-Motion software - visualization of walk

d) Complete final data will be synchronized and processed in VISUAL 3D – C-motion program. This program offers graphic and visual representation of the issue including its mathematical outputs. Figure 5 illustrates possibilities of the program: video-sequence of walking model contains several "landmarks". Clicking on one of them generates diagrams describing progress in the point in cartesian coordinates, derivation, and so on.

Discussion and conclusion

This word does not fit to the topic. The project has just started and it may face many problems in the future. At present we are concentrating on data capture, study of related problems and especially on synchronizing of all devices and programs. We have carried out the first experimental measuring which has brought us general idea of potential problems. The right choice of mathematical method – model seems to be the key part of the project.

Acknowledgements

This research was supported by project SD 2333120024, SD 233 313 0003

References

[1] GERRITSEN, K., NACHBAUER, W., BOGERT, A.: Computer Simulation of Landing Movement in Downhill Skiing: Anterior Cruciate Ligament Injuries. Journal of Biomechanics, Vol. 29, no 7, pp. 845-854, 1996.

[2] GREENWALD, R.: Towards the Creation of a New Release Envelope for Protecting the Knee in Alpine Skiing: Abstracts, XVIIth ISB Congress Calgary, 1999.

[3] JELEN, K., PŘÍBRAMSKÝ, M., KOHOUTEK, M.: Biomechanika a motorické předpoklady alpských disciplín. Praha: UK FTVS, 2001.

[4] KAPS, P., MÖSSNER, M., NACHBAUER, W.: Kurvenradius bei geschnittenen Schwüngen. Institut f. Technische Mathematik, Geometrie und Bauinformatik, Universität Innsbruck, 1999.

[5] KONVIČKOVÁ, S., VALENTA, J.: Biomechanika kloubů člověka a jejich náhrady. ISBN 80-7099-443-6. Praha: Vienala 2000

[6] NACHBAUER, W., KAPS, P. et al.: A Video Technique for Obtaining 3-D Coordinates in Alpine Skiing. Journal of Applied Biomechanics, pp 104-115, 1996.

[7] NACHBAUER, W., KAPS, P.: Belastung des vorderen Kreuzbandes beim Landen im alpinen Abfahrtslauf.

[8] NACHBAUER, W., KAPS, P.: Current Trends in Biomechanics of Alpine Skiing, 2000.

[9] SCHINDELWEIG, K., NACHBAUER, W., SCHLIERNZAUER, T., MOESSNER, M.: Force and moment at the knee joint for carving and parallel turning. Department of Sport science, University of Innsbruck, 2000.

[10] VALENTA, J., KONVIČKOVÁ, S.: Biomechanika člověka – Svalově kosterní systém 1.díl. Praha: ČVUT. 1997.

[11] VODIČKOVÁ, S., LUFINKA, S., ZŮBEK, T., BARBORA, J., MEVALD, J.: Konstrukce měřícího zařízení pro snímání sil v alpském lyžování. Česká kinantropologie, Vol. 7, č. 1, s. 63-73, 2003

[12] www.ihned.cz (web site of the Economic Journal)

[13] www.vunz.cz (Research Institute for National Health)

CREATION OF A HEAD MODEL USING THE FINITE ELEMENT METHOD

P. Vorlíček, F. Lopot, P. Kubový, K. Jelen

Charles University/Dep. of Anatomy and Biomechanics/Lab. for extreme loading, José Mártího 31, 162 52, Prague 6, Czech Republic

petr.pok@email.cz

Abstract: Geometric model setup is the first step in computational model creation. Well done geometric model have to reflect the real object precisely however it have to able calculations on model in a short time, too. These two things are question of compromise between the shapes and mesh complication. Nowadays, there are many softwares available, but for modeling of organs and organ structures the software, which can work with clinical data, is most appropriate. This article inform about using the AMIRA software by creating of virtual model of human brain.

Introduction

For creation of primary geometric 3D model of an arbitrary object there are nowadays many alternatives in selection of software, but the most often used are now the 2D and 3D CAD systems. To build the model it is first necessary to collect the geometric parameters of the investigated object. In case of a human organ measurement of those entries may be very difficult. For this, use of a software able to work with data from non-destructive investigation methods like MRI or CT may be very helpful. Those programmes are designed especially to work with standard formats of pictures from those imaging methods.

Materials and Methods

A good example of such a system is AMIRA, which works with the DICOM format. It's possible to read acquired pictures of the cutting levels and the software creates a virtual model of the investigated part. Quality of the details depends on the distance between neighboring sections. Usually used distance between sections in MRI imaging is about 5 mm. This value is, however, insufficient for 3D modeling in most cases. Distance of max 1.5 mm used for navigation during the invasive surgeries is usually satisfactory also for creation of the model.

For modeling of the tissue structures with the plane orientation in the direction of slices even shorter distance between sections is mandatory. Current devices enable to use 0.5 mm, without any loss of picture resolution. For creation of a model by means of this software it is necessary to define model slice shapes frame by frame. Specification of the areas can be performed manually, using a mouse. There are many tools to facilitate it. Alternatively, also automated model build-up based on picture analysis can be used. It works with intervals of the gray scale density of the pixels selected by the operator. Automatic selection is usually followed by manual correction.

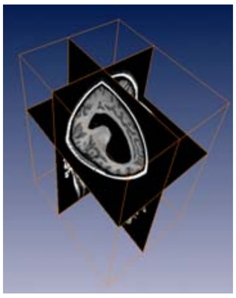
Need of the manual corrections is given by the necessity to eliminate systematic errors. The first systematic error arises from the assigning of the same or nearly the same values of the gray scale to all tissues with similar material structure. It is caused by the technical principle of CT and MRI methods. The second systematic error is caused by merging of two neighboring organs with sufficiently close gray scale (because of use of a finite grey scale interval in the AMIRA software).

The interval of the gray scale density in the selected areas has to be chosen with regard to the density of the neighboring tissues. Very good knowledge of anatomy of the investigated organs and their structures is needed, because some of the tissues are difficult to differentiate. In some pathologic cases material composition of some body structures can be substantially altered.

After specification of areas in all frames the software creates a geometric model of the selected object. The shape of the surface is generated by regression with smooth 3D surface defined by a system of 3D curves.

When the geometric model is developed, computation of a hexagonal mesh follows. It defines the geometry of the surface precisely. After setting the parameters of the mesh, all nodes in the grid get coordinates X, Y, Z, defining their exact

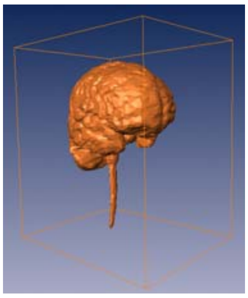
ISSN: 1727-1983 © 2005 IFMBE



position in the model. This mesh can be exported to some software designed specifically for work with the mesh models. There the mesh can be modified according to the modeling needs. Accuracy of the final model is given also by the mesh structure, not only by its density. Erroneous choice of the mesh elements can cause problems on sharp edges or borders during model calculations.

Discussion and conclusions

The virtual model is thus prepared for an import into simulation software (MADYMO, PAMCRASH, etc.). The following parameters and functions have to be defined: reciprocal function between objects, material characteristics, forces, velocities, accelerations, etc. Density of the particular parts of the mesh, number of the reciprocal contacts between objects and the iteration step indicate how difficult the computational model will be. A suitable compromise has to be accepted in the design of any geometric mesh. Inappropriate application can result in unacceptable increase of computational time up to the order of months!



Virtual geometric model built by the AMIRA software can also be utilized to create a physical model. Some systems, e.g. RAPID PROTOTYPING, are capable to produce very sharp plastic figures only from direct data import from AMIRA, too. For these systems, it is no problem to create so difficult objects such as the cranium. Physical models are useful for identification of some mechanical characteristics, for validation of the virtual models and for presentation and teaching purposes.

Acknowledgements

This research is supported by projects SD 2333120024, SD 2333130003.

References

[1] BRANDS, DAVY W.A.: Predicting brain mechanics during closed head impact – numerical and constitutive aspect. Technische Universität Eindhoven, 2002.

[2] NEBUDOVÁ, J.: Kraniocerebrální úrazy. Praha, 1998

[3] LAWSON, A.R., SADEGHI, M.M.: Finite element modeling of blunt or non-contact head injuries, Cranfield Impact Centre, United Kingdom1998

[4] REILLY, P.: Head Injury, Chapman&Hall, London, 1997