APEM journal
Advances in Production Engineering & Management 5 (2010) 2, 117-120
ISSN 1854-6250 Professional paper

THE USAGE OF MEDICAL IMAGES FOR CREATING CUSTOM FE AND CFD MODELS

Dille, J.; De Vleeschouwer, M. & Boelen, EJH
Materialise NV,
3001 Leuven, Belgium

Abstract:
In recent years the demand for customized FE and CFD models has increased rapidly in the biomedical and health care sector. The use of virtual models for a large part eliminates the need for extensive experimentation, allows fast design iteration or exploration of surgical alternatives and reduces the lead-time in product development or the intervention time during surgery. A first step for creating custom FE or CFD models is the acquisition of specific geometrical information of the part that needs to be modelled. For complex structures computer tomography (CT) and magnetic resonance imaging (MRI) are proven techniques for this purpose. Image processing tools have been made available in the Mimics software to extract volumetric information of the structures that are of interest for the FE or CFD analysis. Next, these surface models need to be converted to volume meshes, which can be readily used for running the analyses. Software tools were developed to optimize the quality of the surface mesh prior to the volumetric conversion. Finally a set of tools was created to allow automated, density-based assignment of material properties based on the grey values in the original scan data.

Key Words: Medical Images, Finite Element Analysis, Computational Fluid Dynamics, Mimics

1. INTRODUCTION

The developed approach for creating custom models has been evaluated in a number of cases both for Computational Fluid Dynamics (CFD) and Finite Element (FE) applications. In a first test case, the blood flow through a pulmonary artery of an adult volunteer was studied (in collaboration with Fluent Ltd.). This type of analysis can be used in order to highlight regions of low and stagnant flow, which increase the risk of blood clot formation or aneurysms. The CFD model was used for making velocity plots indicative for the circulation through the artery and surface contour visualization showing shear stresses in the wall of the vessel.

A second example focuses on methods for generating a finite element model (FEM) based on in vivo microfocus computed tomography (CT) images of guinea pig tibiae with a titanium percutaneous implant. Microfocus computed tomography (CT) is a non-destructive technique that enables detailed characterization of bone structure itself and of bone-implant interface [1, 2].

In yet a third example it is shown how to identify respiratory obstruction in performance horses, using CFD tools like airway pressure determination and airflow measurement.
These examples are all cases that feature complex geometries. These geometries are impossible to model in computer aided design (CAD) software, without doing serious concessions to the geometrical accuracy. Based on the proposed approach, both CFD and FE analysis can be performed on the actual patient geometry.

2. METHODS

As a first example of the promising new capability in CFD, flow through a pulmonary artery has been studied. These results are being used to highlight areas that can result in clotting sites or aneurysms. Clots are formed in low and stagnant flow regions where low fluid shear and high residence times are observed. Conditions such as high surface pressure, shear stress, or strong gradients can result in an aneurysm, where the vessel wall bulges outward, forming a pocket. The repair of aneurysms is normally done in a surgical procedure in which a stent is inserted to stabilize the vessel. By using CFD, the stent location and design can be modeled prior to the operation to determine the optimum size and orientation of the device, reducing the risk of unintentional damage and the time required for the procedure.

The actual process of converting patient data into a suitable CFD geometry is not trivial. Many steps are required, and for the pulmonary artery project, several of these involved the use of Materialise's proprietary software Mimics [3]. Mimics converts MRI slices into a 3D solid model, and exports it in stereolithography (STL) format. For the pulmonary artery project, an MRI scan of a chest cavity was obtained from the Sheffield University MRI Unit. MRI scan slices are typically produced in a greyscale pixelated DICOM format, and these were joined together to create a 3D solid model.

Vessels not connected to those of interest, as well as bones and other tissue were removed during segmentation in Mimics and a 3D model was calculated. This 3D model was optimized to in the Mimics FEA module to make it suitable for converting to a volume mesh and exported to a Fluent-mesh. The resulting geometry of the artery was then read into GAMBIT, where a volume mesh was created.

In the second study, custom-made titanium implants were inserted percutaneously in guinea pigs tibiae. CT images were computed in Mimics. Bone, soft tissue and implant structures are represented by voxels with different grey values. In preoperative images, one threshold value was set and voxels representing bone tissue were segmented from surrounding voxels representing soft tissue based on grey value differences. In postoperative images, two threshold values were defined: a lower threshold value to distinguish between bone and soft tissue structures and a upper threshold value to isolate implant material.

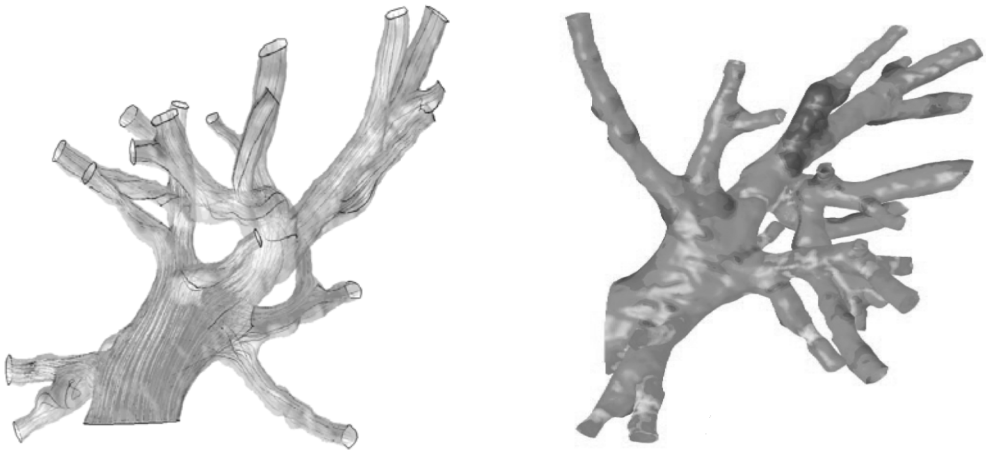
STL files were generated from segmented structures based on each segmentation in the same image-processing software. An STL mesh of the implant was derived in a computer-aided design software (ProEngineer).

The effect of metal artefacts can be eliminated by replacing the post-operative bone STL mesh with the artefact-free pre-operative bone STL mesh. This requires a double registration using the Mimics software. The CAD-based STL mesh of the implant was matched onto the implant STL mesh extracted from postoperative µCT images. The preoperative STL bone mesh was matched onto the postoperative STL representation of the bone. Then the postoperative bone geometry was created with a boolean subtraction of the implant volume from the bone volume. After further adaptation of STL triangulations, they were converted into tetrahedral meshes in a finite element software (MSC. Patran, MSC. Software, Gouda, The Netherlands).

In the third study, a CFD analysis was performed of the nasal cavity of a performance horse in an attempt to identify respiratory obstruction. Starting from CT scans of a race horse's nasal cavity, nasopharynx and larynx, an STL model was created at Cornell University (Ithaca, US). This STL model needs to be optimized to enable the generation of a volume mesh. The volume mesh can than be used for CFD analysis.

3. RESULTS AND DISCUSSION

The physics of blood flow through the body has been the focus of a number of studies over the years, and many of the findings were incorporated into the current model. For example, fluid structure interaction can be neglected for the pulmonary artery, since the thick vessel wall is designed to carry large quantities of blood under (relatively) high pressure, directly away from the heart. Initial checks also confirmed that the flow regime was laminar. Because blood is a non-Newtonian fluid, the shear effect on viscosity needed to be considered. The Carreau-Yasuda model was implemented through a user-defined function (UDF). A velocity boundary was applied to the single large inlet, with a transient, periodic profile that reflects the flow supplied by the heart. Pressure outlet boundary conditions (of equal pressure) were used for the multiple outlets in the model, and the flow split was determined by the vein geometry. Plots of velocity vectors indicate that there are no recirculation regions or dead zones within the artery or it’s primary branches, which was expected, since the scans were taken from a healthy adult (Figure 1A). Surface contours of wall shear stress show an increase near some of the constrictions in the vessels (Figure 1B). However, it is unlikely that these sites would result in the formation of an aneurysm, since the flow in these regions is not directed toward the surface.



A B

Figure 1: Graphical representations of the results of the CFD analysis on the blood flow through the pulmonary arteries, showing the velocity vectors (A) and the wall shear stress (B).

In the second study, general noise is present in the images due to low radiation dose regime. This required some manual editing of µCT slices during segmentation in Mimics. Metal artefacts present in postoperative images influence the grey values of voxels situated in immediate vicinity of implant. However, with the help of the registration tools in Mimics, the STL created in the preoperative images can be used for the postoperative images. After matching the preoperative STL on the postoperative images, also the STL file of the implant can be registered on the postoperative images. Now a Boolean function can be performed in Mimics to create an STL file of the postoperative bone.

The STL file of the postoperative bone and the implant cannot be directly used for the generation of FE meshes because these meshes require very specific characteristics in the geometrical description of the surface to be computed [4]. The Mimics FEA module provides the possibility to reshape the triangles to meet the required quality threshold. This process is called remeshing. Once this remeshed STL is exported to a Patran neutral file, it can be converted to a tetrahedral mesh in MSC.Patran. The tetrahedral mesh can then be imported again in Mimics and the grey values in the images can be used to assign materials to the elements of the volume mesh. The Mimics FEA module provides tools to relate the grey value of an element to a density and this density to material properties like an e-modulus and a poisson coefficient. The volume mesh with the material assignment is then ready to be used in the finite element analysis.

In the third study, the surface mesh needs to be optimized, since sharp or thin-walled areas are intrinsic to human and animal nasal geometry. These require a very fine surface mesh to be able to generate a volume mesh. Normally it takes several weeks to optimize the mesh prior to CFD analysis by manually moving and reshaping a lot of triangles, but using the remeshing capabilities in Mimics FEA module the time needed was reduced to a few days. First a global remeshing operation was performed, assuring the majority of the triangles conform to the required shape quality. Next, sharp geometry features are automatically selected and grouped on which local remeshing and smoothing operations were performed, until the complete mesh was suited for CFD (Figure 2A). It was then exported to GAMBIT to produce the volume mesh. The analysis was done in Fluent (Figure 2B), after setting the appropriate boundary conditions for inlet and outlet.

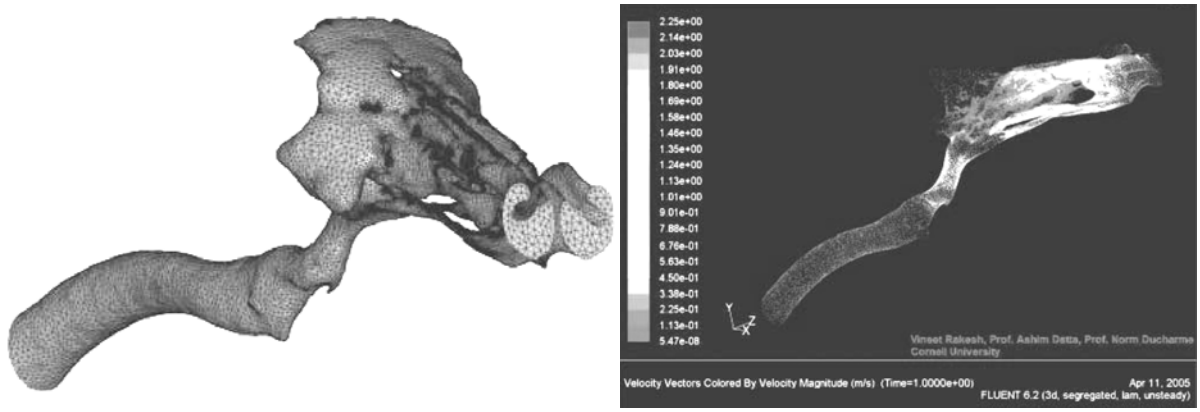


Figure 2: Remeshed surface mesh of the horse nasal cavity (A) and colored visualization of the velocity vectors as computed by the CFD analysis (B).

4. CONCLUSION

Overall, this emerging technology shows promise for medical procedures in the future, since it can provide important information specific to an individual using non-invasive tools. The efficiency and accuracy of FE and CFD mesh generation was improved by switching from a completely CAD-based approach described previously [5,6] to an STL-based approach. This STL-based approach enables performing FE or CFD analysis on accurate, image-based patient geometry, which is very valuable in the medical field since it often features very complex anatomical shapes.

REFERENCES

[1] Kiba, H.; Hayakawa, T.; Oba, S.; Kuwabara, M.; Habata, I.; Yamamoto, H. (2003). Potential application of high-resolution microfocus X-ray techniques for observation of bone structure and bone-implant interface, *Int J Oral Maxillofac Implants*, Mar-Apr 18:2 279-85

[2] Van Oossterwyck, H.; Duyck, J.; Vander Sloten, J.; Van der Perre, G.; Jansen, J.; Wevers, M.; Naert, I. (2000). Use of microfocus computerized tomography as a new technique for characterizing bone tissue around oral implants, *J Oral Implantol*, 26:1 5-12

[3] Mimics, v10.11. Medical image processing software. Materialise NV, Leuven, Belgium. www.materialise.com/mimics

[4] Bechet, E.; Cuilliere, J.-C.; Trochu, F. (2002). Generation of a finite element mesh from stereolithography (STL) files, *Computer-Aided Design*, 34: 1-17

[5] Muraru, L.; Jaecques, S.V.N.; De Smet, E.; Van Oosterwyck, H.; Wevers, M.; Naert, I.; Vander Sloten, J. (2003). Micro-CT based finite element modelling as an in vivo follow-up tool for adaptive bone response around implants in guinea pig tibiae, ESEM 2003 conference, Halle, Germany, 18-21 Sept. 2003

[6] Jaecques, S.V.N.; Muraru, L.; De Smet, E.; Van Oosterwyck, H.; Wevers, M.; Naert, I.; Vander Sloten, J. (2003). Micro CT-based finite element analysis: an enhanced follow-up tool for bone remodelling around threaded implants, International Congress Series, 1256 (2003), 1356