

Simulation of Endonasal Airflow Based on Patient-Specific Data

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Abstract

Computer-assisted planning systems based on patient-specific tomography data have proven to be useful in several medical fields. A patient's tomography data can be shown in several views and can be enhanced with additional information useful for the planning process. The STAN (Simulation Tool for Airflow in the human Nose) system overlaps patient data and CFD (computer fluid dynamics) data resulting from flow simulations of the airflow in the patient's nose channel.

To verify the simulation results, experimental investigations and measurements are made in nasal models. Silicon models of a patient's nose channels are made to analyze flow characteristics. The CT or MR scans of the same patient are used as input data for the simulation. The experimental outcome is compared to the simulation results to validate this diagnostic approach.

1. Background

»L'essentiel est invisible pour les yeux« the fox said to the little prince, but it is not certain that he meant a rhinologist looking at a patient's tomography slices and trying to understand the reasons for his pathologic endonasal airflow. However, the lack of diagnostic tools suitable for providing insight into patient-specific flow characteristics of the endonasal airflow is one of the main problems in functional diagnosis. Diagnostic methods currently used, like acoustic rhinometry, do not provide the necessary information for flow analysis, because only the diameters and not the 3-D geometry of the nose channel are taken into account. But the flow pattern in the nose plays an important part in respiration. The nose inhales air at a speed of up to 20 m/s. The air is warmed, moistened and cleaned. The endonasal mucosa, which lines the cavum, is responsible for this respiratory

function. The turbulent kinetic energy of the flowing air has to be balanced to contact the mucosa in an appropriate proportion. In a laminar case, the air is flowing parallel to the surface of the nose cavities. In this case, only particles near the surface get in contact with the mucosa. In a turbulent case, air contact with the mucosa can be too intense and cause desiccation.

This is the reason a cooperative project between the Darmstadt University of Technology and the ENT Clinic of the University of Greifswald was started, which tries to use Finite Element Methods for the simulation of patient-specific endonasal airflows. Finite Element Methods have made great progress within the last years, and their use has become standard in the area of engineering, for example, for the optimization and verification of aerodynamic properties.

2. Simulation Tool for Airflow in the human Nose

The STAN (Simulation Tool for Airflow in the human Nose) should allow a precise diagnosis of pathologic respiration caused by a malformed nose. For the usability of the simulation result, it is important to have an intuitive and tailored visualization software that provides the physician with the possibility of analyzing the huge and complex data sets. The STAN User Interface consists of a display area including three orthogonal views, a 3-D view, and functional areas to query status information and to control the planning session. In general, the planning procedure starts with loading and checking the data set. Furthermore, the surgeon is

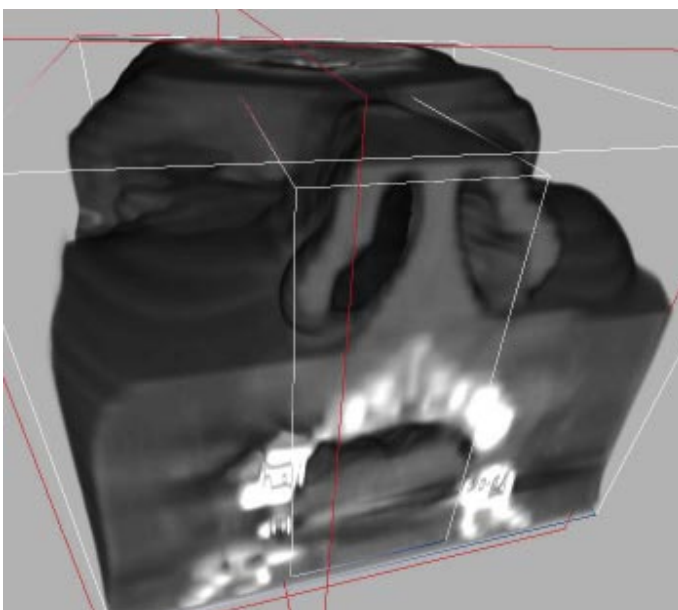


Figure 1:
Visualization using
the volume renderer



Figure 2: Comparison of simulation result and experimental outcome

able to navigate through the 3-D data set and to define the contours describing the geometry of a nose channel. These contours are interpolated to obtain the flow volume used for the flow simulation. The flow volume, derived from a patient's tomography scans, is discretized into a numerical grid. The quality of the grid is important for the quality of the results. The commercial FEM package FLUENT 4.0 is used to perform the simulation. An intuitive and tailored visualization software that allows the physician to analyze the huge and complex data sets is important for the usability of the simulation result. With the tomography as well as the simulation data, there are two different sources of volume data that have to be considered. To visualize these large amounts of data, a volume renderer supporting the volume slicing technique has been developed. (cf. Figure 1)

The data is stored as a set of parallel cutting planes. Textures holding the gray values (in the case of tomography data) or the color values (e.g., representing the air speed) are mapped onto these cutting planes. This technique is used by the STAN visualization system. It shows the tomography as well as the simulation data in the sagittal, coronal and transversal cut. The fourth quadrant offers the possibility of rendering vector plots, streamlines, and isosurfaces. Slices can be inserted into the flow channel illustrating speed distribution on the 2-D plane. Another possibility of displaying the simulation result is the use of equipotential contours showing airspeed or turbulent kinetic energy on the surface of the nose cavity.

3. Validation

To verify the simulation results, the University Hospital in Greifswald performs experimental measurements with nasal models. Silicon models of a patient's nose channels are made to analyze flow characteristics. The CT or MR scans of the same patient are used as input data for a simulation (cf. Figure 2).

For fluid, water is used for the experimental simulations. In the simulation, the fluids air and water (for comparison) can be chosen. Experiment and simulation show similar characteristics in the distribution of velocity fields and turbulence, but some parameters still remain unconsidered. Additionally, at the University Hospital in Greifswald, studies are being carried out to measure the variation of the nose's hydraulic diameter during a respiratory cycle, which is also very important for the simulation.

The first validation results are motivating further investigations. So far, only physiologic cases have been considered; the next step will be the validation based on pathologic cases. In further developments, the diagnostic component of STAN will be supplied with an operation-planning component: based on the tomography data, the planned surgical intervention can be described. The simulation is performed for the preoperative pathologic case and the changed geometry of the nasal channel, described by the planning results, that can be expected after the surgical intervention. The goal is to study if the surgical outcome is predictable.

4. Future Work

The method of biomechanical simulation is not restricted to rhinosurgical applications. Biomechanical simulations on patient-specific data are performed to analyze the load distribution in the human spine. The simulations will be integrated into a complex planning system designed to support the surgeon in specifying the type and positioning of pedicle screws in computer-assisted pedicle screw insertion.

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