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3-D Simulation of Form and Function of Lung

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Computer visualization is not only proven to be a valuable tool to interpret data sets coming from from various scanner systems, but also for the investigation of simulated data based on physical, biochemical or mathematical resources. We describe the necessary analytical and computational steps required for a simulation and visualization of a complete lung model of rat or human, based on macroscopical and microscopical measurements for the conductive and respiratory parts of the lung, respectively. To study flow of air and the oxygen uptake, a set of mass transport equation is solved iteratively.

The structure of the mammalian lung is far too complex for a complete analytical investigation of an individual organ, beside the different preparative ways required for studying macroscopical and microscopical aspects. Instead, some basic patterns of the structural organization have to be deduced, which then can be used by the computer to simulate a complete model. The macroscopical, conductive part of the lung is based on studies of corrosion cast models. Stereo images of such models featuring the bronchial tree were analyzed for their branching pattern with the STERECON System, developed at the New York State Department of Health in Albany. Lung segments of interest were traced stereoscopically using a two monitor stereo display system, a digitizer and a 3-D cursor. The end points of the segments, the length, diameters and the angle of branchings can be determined giving a 3-D sceleton of the conductive air-ways. Analyzing the angle/length/diameter relationships gives some basic fractal properties of the branching pattern.

For a quantitative analysis of the respiratory system of the lung, in particular the pulmonary acinus, the imaging of volumes with a computer-guided reference system allows to study the respiratory part of lung, as described in the preceeding abstract (A. Kriete: Investigating large volumes of lung by computer-guided 3-D image compositing in confocal microscopy). The measurement of branching angles and lengths and the overal topology is studied by 3D-TOP, a software developed at our image processing laboratory in Giessen. This software evaluates connectivities between corresponding contours in adjacent sections are connected, based on bijective correspondance analysis. These connectivities form a topological sceleton of the structure and indicate nods and branches that are the backbone to analyze volume and sur-face. These are parameters necessary to describe the function of the respiratory system.

The computer based simulation of the structure of a complete lung starts with the 3-D implementation of the main bronchial segments as measured from the cast model. All daughter branches are added by the computer program, using fractal properties. Such a 3-D computer generated graphical model can be displayed from all sides and the effect of variation of angles and lengths can be easily studied. Typically, such a model of the human lung model features 75000 segments.

Based on the 3-D structural model functional attributes can be added. One example is the flow of air, which is predicted for all segments using the diameter and the dead space relation of daughter branches. To study the oxygen uptake, the mass transport equations have to be solved. Mass transport has to include convection, diffusion and oxygen uptake. Since this set of differential equations can not be mathematically solved, the process of inhalation and exhalation can only be computed iteratively. For a stable solution, up to 10000 time steps have to be calculated for each of the segments. Using a Silicon Graphics

Challenge L computer system with 2xR4400 processors, this takes about 30 hours of computing time. The final oxygen distribution is visualized at the 3-D structural model. We give examples, how the oxyen distribution in human and rat looks like under various breathing conditions.

REFERENCES

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