CREATION OF PREMATURELY BORN INFANT AIRWAYS MODEL BASED ON X-RAY CT AND MRI SCANS

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Abstract: Proposed contribution deals with the creation of infants' airway model, based on available clinical MRI and CT scans of newborns. For this purpose, an algorithm which extracts the airway geometry was developed. Resulting geometry is consequently transformed to the airway model in stereolithography format, suitable for further analysis. The algorithm was tested on the data which correspond to an infant born in 30 weeks of gestation and scanned 14 days after birth. Thus, the model corresponds to the 32 weeks old infant.

Keywords: Airway model, Neonatology, Medical imaging, Image processing

1 INTRODUCTION

Insufficient lung development is still the highest mortality factor in prematurely born babies. Fortunately, there are breathing support devices which help infants to endure the critical phase of lung development. However, neonatologists often struggle with the correct settings of these supporting devices to provide maximum possible breathing support. The aim of this contribution is the development of a methodology for airway model creation. Created models based on proposed the methodology are suitable for the evaluation of anatomical parameters and understanding lung function. Lung function evaluation is based on realistic physical or numerical simulations [1]. Results of these simulations can help to explain the behaviour of the respiratory system in preterm infants under certain breathing conditions. This approach of airway system modelling is suitable to avoid ethically problematic experimental tests on preterm infants. The geometry construction is based on MRI (Magnetic Resonance Imaging), and X-Ray CT (X-ray Computed Tomography) scans. Based on these scans, the airway geometry was extracted according to proposed segmentation techniques, and the final model in stereolithography format was exported.

2 OBTAINED DATA

The geometry is based on two diagnostic measurements. The first one is an MRI scan of the head of 2 weeks old patient born in 30. week of gestation which also includes trachea up to first bronchioles branching. The second scan is CT of lungs with the one-month-old infant with an unknown week of gestational age. This dataset was chosen from all available datasets due to the best dimensional similarity to fundamental MRI head scan. The similarity was evaluated as trachea dimensions in the three selected trachea cross-sections. Proposed dataset combination is necessary because no dataset containing both - upper and lower airways, was available to this study. Both datasets are reconstructed separately for every orthogonal plane with the anisotropic voxel size. In the case of CT data, three additional reconstructions are available thanks to contrast agent imaging. The voxel size of the MRI data is 0,5 x 0,5 x 2,5 mm and CT data 0,34 x 0,34 x 1,25 mm respectively.

3 IMAGE PROCESSING

In order to create the airway geometry, it is necessary to pre-process data for consequent airways segmentation. Infants' airway segmentation is a challenging task due to insufficient data quality for standard segmentation methods. Final geometry export to the model in stereolithography format was applied with gaussian smoothing. Smoothing filter works iteratively three times with gaussian kernel size 5.

3.1 IMAGE PREPROCESSING

Image pre-processing consists of image resampling and image filtering. Image resampling is executed to achieve isotropic voxel resolution 0,2 mm for all available reconstructions. The resampling factor for interpolation to voxel size 0,2 mm was chosen to reach the best compromise between spatial and contrast resolution. This resampling step does not allow to segment tinier structures but reduces stair-step artefacts which arise from big voxel size.

The second step of image pre-processing is image filtering. Based on [2] was chosen bilateral filter for image enhancement. The bilateral filter is nonlinear and is used for image smoothening and noise reduction while preserving edges. The kernel of filtration here depends not only on the distance but also on the intensity of the surrounding pixels related to the investigated pixel. In this case, the Gaussian kernel with standard deviation = 3 and size of the filter = 5 was chosen.

3.2 IMAGE SEGMENTATION

Segmentation of both image datasets is based on custom-written Region Growing algorithm [3], developed in Matlab programming environment. The algorithm itself is automatic, and only manual correction of segmentation in locations with insufficient contrast is essential. The voxel selected as an initial seed is always in the region, where its' 26-neighbourhood has the lowest intensity. In MRI data of upper airways, this region corresponds to the nasal cavity. In CT data of lower airways, this region corresponds to the trachea, which is the standard location for initial seed placement in case of lower airways segmentation. The 26-neighbourhood mask ensures that no noise voxel will be selected as an initial seed. The region growing process itself utilizes an adaptive threshold to find voxels corresponding to the air which is contained in airways. The growing segment proceeds through the airways until it encounters a tissue or (developing) bone. Additionally, the algorithm detects leakage of the growing segment beyond the airways. Based on intensity values in the mask surrounding the considered voxel, lung parenchyma can be recognized and growing in this part of the volume is stopped.

The proposed algorithm works properly in regions with sufficient air/tissue contrast and in case of the tracheobronchial tree up to the bronchioles in 1,2 mm of its' diameter. This diameter corresponds to the second generation of branched bronchioles. Additional bronchioles were segmented by fine manual segmentation (Fig.: 1.). The Segmentation algorithm is executed on all available reconstructions of a particular dataset. All obtained masks are then thanks to the equal voxel size merged to obtain final segmented geometry.

3.3 IMAGE REGISTRATION

Image registration part of the algorithm works semi-automatically. At first, trachea volume in both datasets is detected by the algorithm thanks to its cylindrical shape. In the second step, the centres of trachea's mass are overlapped. This pre-alignment step facilitates further manual final registration. Manual registration is executed based on the first airway branching. The main task is to shift and rotate segmented lower respiratory tract data to overlap the trachea volume as much as possible. The

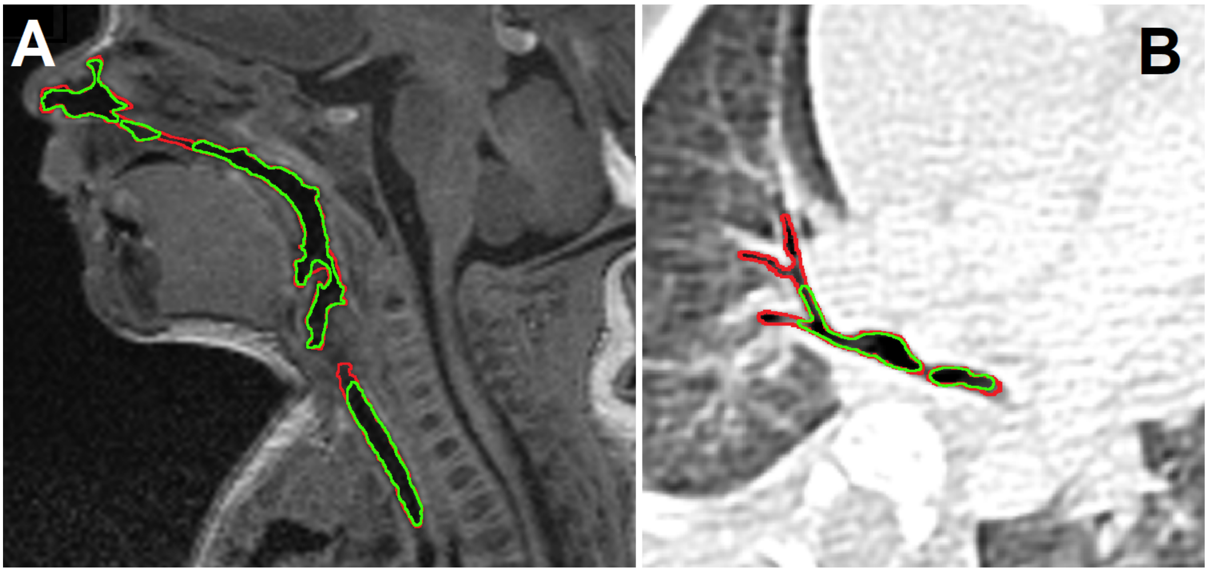

Figure 1: Segmented airways: Green line - automatic segmentation by Region Growing, Red line - fine manual adjustment. (A) MRI of head - sagittal view, (B) CT of lungs - transversal view

overlapping part of the trachea, which is present in both datasets was preserved form CT dataset due to higher air/tissue contrast, and thus higher relevance of trachea segmentation. Despite, the trachea dimensions are in both datasets approximately identical. The final location of the datasets connection is chosen based on the maximal restriction of stairstep artefact. The tilt of both datasets was based on the knowledge that the nasal cavity should be perpendicular to the frontal plane of lungs. Moreover, the primary bronchi of both datasets have to overlap.

4 RESULTS

Based on literary research, the algorithm for image quality enhancement, improved region growing segmentation and image pre-alignment, was developed. The Proposed algorithm is able to distinguish airways, including bronchioles up to 1,2 mm in diameter. The dimension 1,2 mm is given by the minimum sufficient contrast resolution, although the voxel size is thanks to isotropic resampling 0,2 mm. The registration procedure is semi-automatic due to the necessity of manual translation and rotation of the lower respiratory tract segmented volume. The segmented and registered geometry is converted to .stl format, suitable for export to downstream systems for rapid prototyping and further analysis. The voxel size 0,2 mm is small enough to avoid sharp edges in the vertex representation. Nevertheless the gaussian smoothing was applied to ensure smooth transients between all structures, especially in the region of datasets combination. Since this conversion, the geometry is represented as a model corresponding to an infant born in 30 weeks of gestation and scanned 14 days after birth. Thus the model corresponds to the 32 weeks old infant (Fig.: 2). The model includes whole airways except for the oral cavity, which is not possible to recognize due to spatial and contrast resolution of available datasets. The oral cavity is in the case of modelling infants' airways negligible due to administration of breathing support via nasal cannulas. The model is as a representative, as the segmentation is valid. The datasets registration does not influence the parameters of the model because the age of both infants was very similar. The validity of the segmentation was consulted and approved with a physician-newborns radiologist. All of the main structures are included in segmentation, only small details below the scan resolution limit cannot be detected, but this imperfection will not significantly influence the model properties.

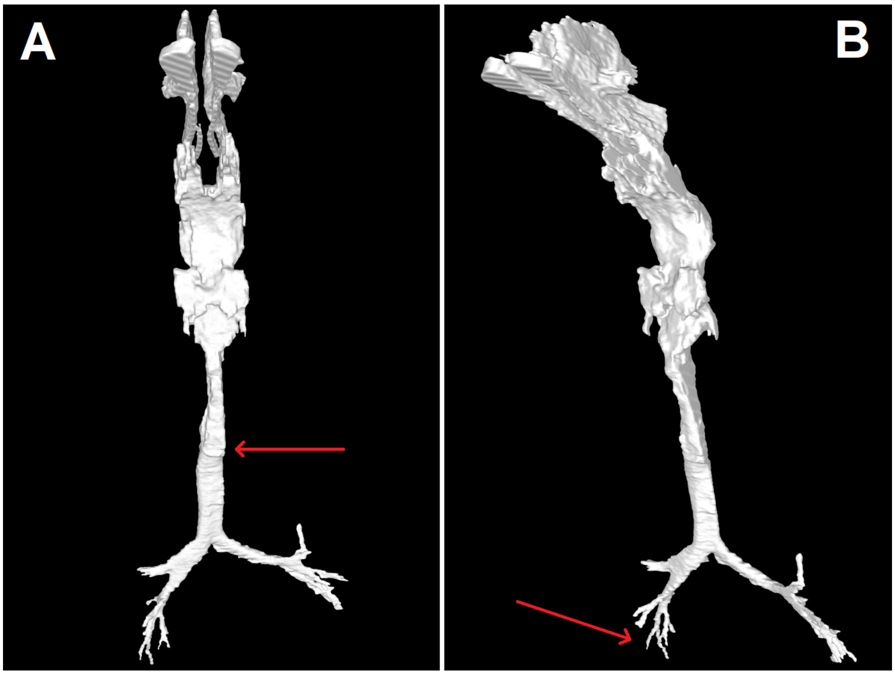

Figure 2: Resulting infant airway model. (A) Frontal view, red arrow: location of datasets combination. (B) 45° rotated view, red arrow: third generation of bronchioles branching added by fine manual segmentation.

5 CONCLUSION

Based on available datasets, an algorithm was developed to create a model of the airways of prematurely born infants. The procedure is based on image quality enhancement, airways segmentation and registration of required datasets. The segmentation was executed separately for the upper and lower respiratory tract, in all individual image reconstructions. These individual segmented datasets were consequently registered into the whole respiratory tract. Registration was executed according to the primary bronchi location. Subsequently, were these segmented data exported into .stl format, suitable for rapid prototyping and anatomical parameters analysis. The proposed algorithm will be utilized for further models of infants airways creation.

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