3-D Visualisation of CT-data for Surgical Planning in Trachea Resection: Proof of Concept

Hertel, I. [a], Strauß, G. [a], Schulz, T. [b], Dornheim, J. [c], Cordes, J. [c], Krüger, A. [c], Tietgen, C. [c], Burgert, O. [d], Dietz, A. [a], Preim, B. [c]

[a] Department of Oto-rhino-laryngology, Leipzig University, Germany

[b] Department of Radiology, Leipzig University, Germany

[c] Institute for Simulation und Graphiks, Otto-von-Guericke-Universität Magdeburg, Germany

[d] BMBF-Innovation Center Computer Assisted Surgery ICCAS, Leipzig University, Germany

…

Abstract. In this study we designed a software to segment and visualise CT-data for surgical planning of trachea resection. Resection planning requires exact anatomic knowledge in all three dimensions for each individual patient. Semiautomatic image analysis algorithms like live-wire, region-growing and watershed transform were integrated and set in a fixed segmentation-order to simplify segmentation. A planning software contained multiple interaction possibilities to demonstrate the results in a 3-dimensional kind. Measurement tools to compute extents, values and distances were integrated. Segmentation was done by surgeons themselves. The segmentation results were compared with the intraoperative and histopathologic findings. The benefit was proofed by using the ICCAS assessment system "Level of Quality" (LOQ). This system allows an evaluation of the gain of information compared to standard 2-D representation methods for surgical planning.8 patients with stenosis of trachea were evaluated in this study, where 3 patients were undergoing resection of the stenosis.

The average time required for segmentation and visualisation was about 35 minutes, indeed professional image processors needed less time for post-processing than clinical surgeons.

Segmentation results were proofed to correspond with intra-operative and histopathologic findings. The results of preoperative surgical evaluation of trachea stenosis based on 2-dimensional CT-data or diagnostic tracheoscopy differed from histopathologic findings. In all cases stenosis was estimated to long. Measurements based on computer-guided 3-dimensional reconstruction corresponded exactly to histopathologic findings. The Level-of-Quality-value of 70 showed a significant gain of information and thereby a benefit in comparison to standard 2-dimensional representation methods of CT-data.

In some cases surgical intervention was only made possible by preoperative planning on reconstructed CT-data. Interdisciplinary discussions were shortened and simplified by showing 3-dimensional visualisation results to colleagues. Besides the received results were used for patients` information and students` teaching.

Keywords:
trachea resection; 3-dimensional; visualization; segmentation; surgical planning; ENT-surgery; computer assisted surgery; post-processing

1. Introduction

Stenosis of the trachea represents a frequent complication after tracheotomy or long time artificial respiration. Symptomatic stenosis needs surgical resection and reconstruction. Resection planning requires exact anatomic knowledge in all three dimensions for each individual patient. Nowadays resection of stenosis is planned preoperatively by slice-by-slice inspection of 2-dimensional radiological data. Diagnostic endoscopy gives additional information about the pathology but includes a high risk of mucosal swelling with increasing dyspnea and therefore not usable in all cases. Common radiological workstations include simple tools for manual segmentation and limited possibilities of visualisation. Herewith no image postprocessing is practicable elsewhere than directly at the radiological workstation so that clinical usability is limited. Image postprocessing takes a long time if these manual segmentation and visualisation-methods are used. 3-dimensional reconstructions generated by radiologists, having another point of interest than surgeons, are sometimes rather simple and frequently not sufficient for clinical application. Transferring post-processed data to surgeons is another obstacle that limits practicability in clinical routine.

This study investigates different possibilities of semiautomatic segmentation and visualisation-methods of CT-data of the trachea by surgical users and their benefit in trachea resection planning.

2. Methods

We designed a new software independent from CT-workstations, called NeckVision, to segment and visualise computer tomography data. The integrated semiautomatic image analysis algorithms are based on the ILab-library developed by MeVis (Bremen, Germany). CT-data required for regular diagnostic have to be available as dicom-data. No other specifications and no fixed protocol were needed. Semiautomatic algorithms of segmentation like modified watershed transform, live-wire and region-growing were integrated in this software and adapted to the special requirements in ENT-surgery. The modules were summarized in an user-friendly interface with fixed segmentation-order to simplify segmentation. Manual segmentation was made possible for difficult cases.

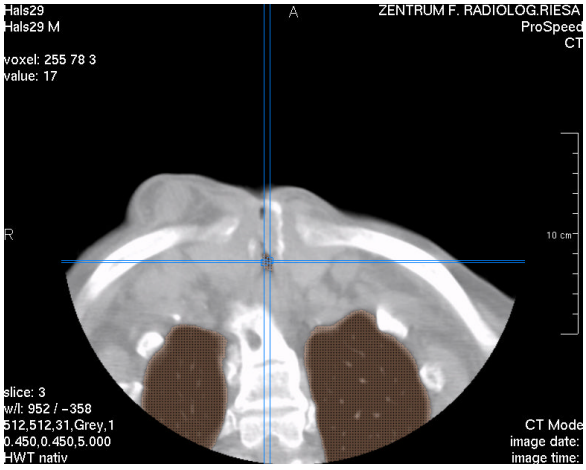

Fig. 1:
2-dimensional CT-slice; stenosis of the trachea

Additionally we designed an operation planning software for demonstrating the results after segmentation, called InterventionPlannerENT. Different kinds of visualisation and interaction possibilities like rotation in all dimensions, choice of transparency-values and colours, object selections as well as measurement tools allowed an improved individual surgical planning.

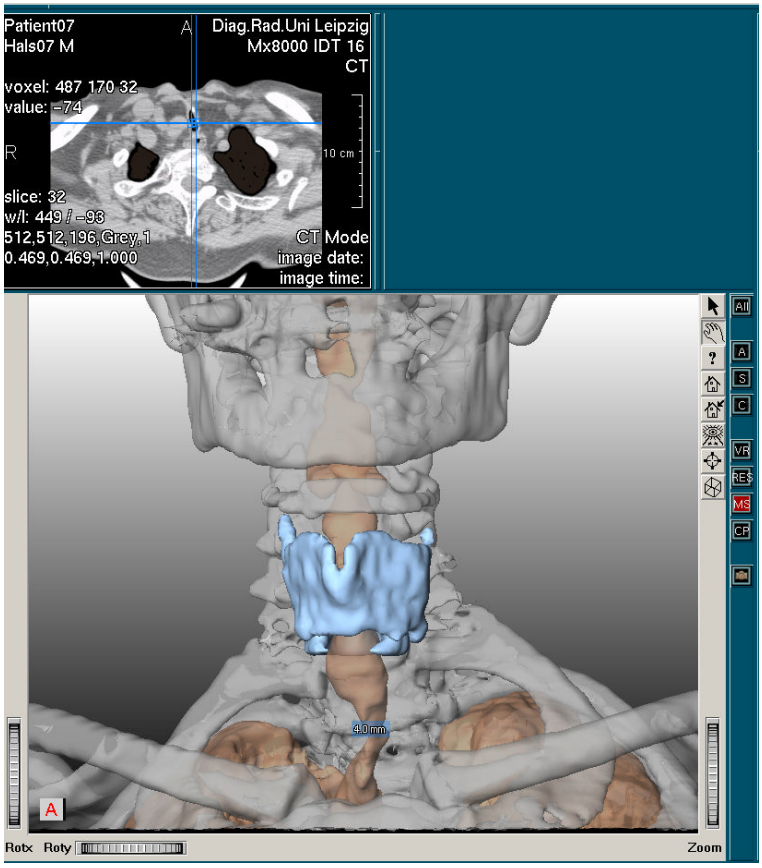

Fig. 2:
Screenshot of the InterventionPlannerENT; 3-dimensional visualisation of trachea stenosis with minimal diameter of 4mm reconstructed from CT-data; trachea, lung (brown), larynx (blue) and bones (grey) and the corresponding 2-dimensional original slice were shown

Segmentation and visualisation was done by surgeons themselves and additionally by professional image processors. Surgeons had the possibility to explain their requests to the computer scientists specialised on image post-processing by using a questionnaire. The trachea and adjacent anatomic structures like bones, larynx, thyroid gland, muscles and vessels were segmented and visualised in a 3-dimensional kind. Diameter, length and position of stenosis were measured. The results were represented as movie and screen-shots online, so that the surgeons could recall them at once.

The time requirement as well as the results of segmentation and visualisation were fixed and compared to the intraoperative and histopathologic findings. The benefit was proofed by using the ICCAS assessment system “Level of Quality” (LOQ). This system allows an evaluation of the gain of information compared to standard 2-D representation methods for surgical planning.

8 patients with stenosis of trachea were evaluated in this study, where 3 patients were undergoing resection of the stenosis.

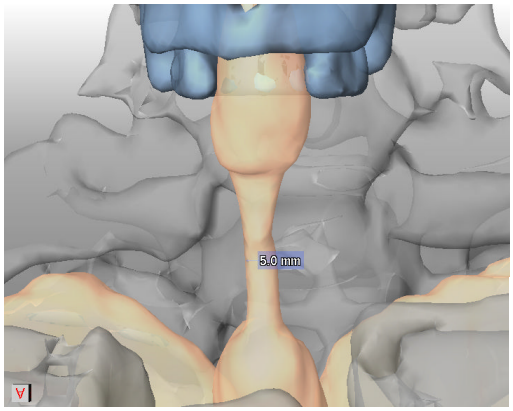

Fig. 3:
Measurment result; diameter of the stenotic segment of the trachea in mm
(bones = grey; trachea = brown; larynx = blue)

3. Results

The trachea, larynx, lung and bones were segmented and visualised in a 3-dimensional kind. The used colour for each structure was standardised for a rapid recognition. Different levels of transparency were used to prevent that objects in the front cover up structures in the back. The length, diameter and position of the stenosis of the trachea were measured and displayed. The average time required for segmentation and visualisation was about 35 minutes, indeed professional image processors needed less time for post-processing than clinical surgeons. The results were displayed as pseudo-3-dimensional pictures or movies.

The operation planning software, InterventionPlannerENT, allowed individual rotation and choice of presented 3-dimensional structures and measurement results as needed. Topographic attachment of patients individual pathology and thereby a secure classification of possibility and extent of trachea resection was enabled.

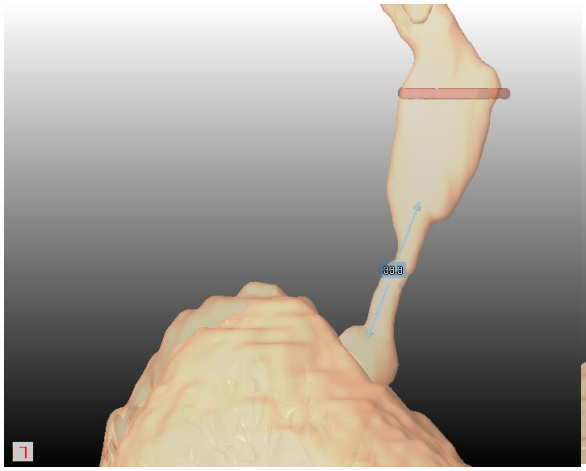

Fig. 4:
Measurement results (blue); Length of the stenotic segment of the trachea in mm; view from the left hand side;
(trachea and lungs = brown; glottis = red)

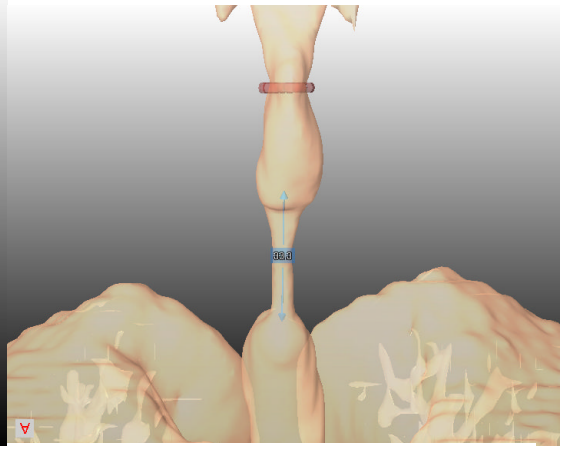

Fig. 4:
Measurement results (blue); Length of the stenotic segment of the trachea in mm; view from the front;
(trachea and lungs = brown; glottis = red)

This kind of 3-dimensional visualisation was characterized by its compressed content of information and quick comprehension of the patients individual pathology. Segmentation results were proofed to correspond with intra-operative and histopathologic findings. The results of preoperative surgical evaluation of trachea stenosis based on 2-dimensional CT-data or diagnostic tracheoscopy differed from histopathologic findings. In all cases stenosis was estimated to long. Measurements based on computer-guided 3-dimensional reconstruction corresponded exactly to histopathologic findings.

The Level-of-Quality-value of 70 showed a significant gain of information and thereby a benefit in comparison to standard 2-dimensional representation methods of CT-data. The advantage was made clear for individual and detailed surgical planning and common discussions with other medical specialists. For this reason the described visualisation-methods were established for trachea surgery in the department of oto-rhino-laryngology at Leipzig University.

4. Conclusion

The clinical use of virtual 3-dimensional illustrations for individual surgical planning of trachea resection was pointed out by this study. The possibility of image-post-processing by surgeons itself was proved. Surgical planning was simplified and precised by using 3-dimensional reconstructions. The results allowed a secure operation planning with indication of resection-possibility, extent of the stenosis, and maybe occurring risks. Patients' safety during surgical intervention was enlarged as well as before intervention because tracheoscopy as diagnostic preparation additionally includes a high risk of complications. In some cases surgical intervention was only made possible by preoperative planning on reconstructed CT-data. Interdisciplinary discussions were shortened and simplified by showing 3-dimensional visualisation results to colleagues. Besides the received results were used for patients` information and students` teaching.