Pre-operative Segmentation of Neck CT Datasets for the Planning of Neck Dissections

Jeanette Cordes[a], Jana Dornheim[a], Bernhard Preim[a], Ilka Hertel[b,c], Gero Strauss[b,c]

[a] Department of Simulation and Graphics, Faculty of Computer Science,
University of Magdeburg, Universitaetsplatz 2, 39106 Magdeburg, Germany;
[b] Ear-Nose-Throat-Department, University Hospital of Leipzig,
Liebigstrasse 10-14, 04103 Leipzig, Germany;
[c] Innovative Center Computer Assisted Surgery,
Philipp-Rosenthal-Strasse 55, 04103 Leipzig, Germany

Please place markers into the bones.
If necessary adjust the value for the lowest greyvalue of the bones until you are satisfied with the segmented result.
Then save the result.

Please click 'Load Structures' to load the segmentation results.
Then you can turn on and off the results of the segmented structures, measure them and change their transparency in 2D and 3D.

ABSTRACT

For the pre-operative segmentation of CT neck datasets, we developed the software assistant NeckVision. The relevant anatomical structures for neck dissection planning can be segmented and the resulting patient-specific 3D-models are visualized afterwards in another software system for intervention planning.

As a first step, we examined the appropriateness of elementary segmentation techniques based on gray values and contour information to extract the structures in the neck region from CT data. Region growing, interactive watershed transformation and live-wire are employed for segmentation of different target structures. It is also examined, which of the segmentation tasks can be automated. Based on this analysis, the software assistant NeckVision was developed to optimally support the workflow of image analysis for clinicians. The usability of NeckVision was tested within a first evaluation with four otorhinolaryngologists from the university hospital of Leipzig, four computer scientists from the university of Magdeburg and two laymen in both fields.

Keywords: Segmentation, Pre-operative Planning, Neck Dissection

1. INTRODUCTION

Malignant tumors of the oral, nasal or the throat cavity represent a great epidemiological problem in western countries. Due to the tumor position, the risk of developing lymph node metastases in the neck region is very high.[1] Therefore a fast and effective treatment of enlarged (i.e. potentially malignant) lymph nodes is essential. The treatment with the best long-term results is a surgical intervention - a neck dissection - which is feasible if major blood vessels are not infiltrated. Up to now neck dissections, that means resections of the tumor and the affected lymph nodes, are often planned on the basis of axial slices of computed tomography (CT) or magnetic resonance imaging (MRI) data. However, the detection of enlarged lymph nodes in the 2D data is difficult for surgeons. Thus it is possible that affected lymph nodes are not recognized and eventually a surgery has to be canceled because of previous misinterpretation of the patient's operability.

Further author information: (Send correspondence to J. Dornheim)
J. Dornheim: E-mail: dornheim@isg.cs.uni-magdeburg.de, Telephone: +49.391.6711164

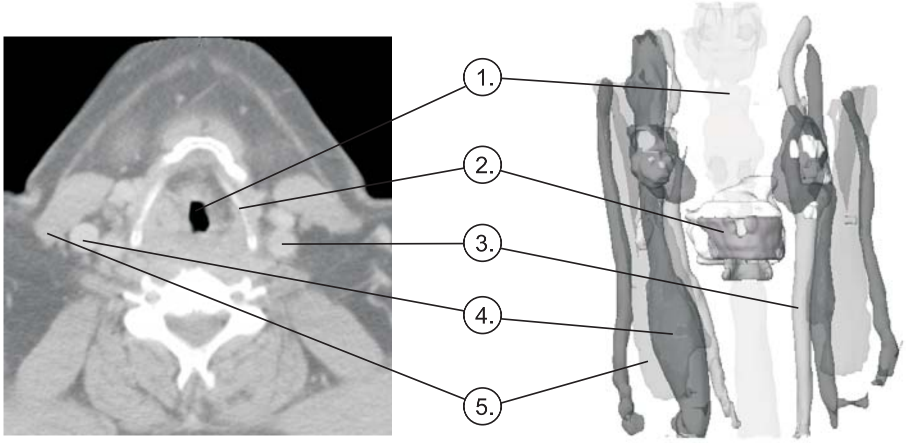


Figure 1. CT dataset of the neck (left) and 3D visualization of the segmentation results (right). 1) pharynx, 2) larynx (thyroid cartilage), 3) A. carotis, 4) V. jugularis interna, 5) M. sternocleidomastoideus

The following structures were identified as being relevant for neck dissection planning by discussions with the physicians:

- the primary **tumor** (size, location),
- all **lymph nodes** larger than 1cm (number, location, size),
- **blood vessels**, in particular the V. jugularis and A. carotis (risk structures),
- **muscles**, in particular the M. sternocleidomastoideus (risk structure),
- **nerves**, in particular the N. vagus, N. hypoglossus, N. accessorius (risk structure),
- **salivary glands**, in particular the Gl. submandibularis and Gl. parotis (context structure),
- the **bones**, in particular the mandible, clavicle and vertebrae (context structures),
- the **pharynx**, **trachea** and **lungs** (context structure).

To support the surgeon's treatment decision by a pre-operative 3D visualization of the patient's anatomy and pathology, we developed the software assistant NeckVision which integrates carefully selected segmentation methods. In all clinical cases where pre-operative image analysis was accomplished, the main focus lay on the primary tumor and the enlarged lymph nodes. Additionally, the *risk structures* are important. These are primarily the surrounding blood vessels, muscles, and nerves. Bones, salivary glands, and the air filled structures serve for spatial orientation in the 3D visualization of the segmentation results. With NeckVision lymph nodes as well as the adjacent *risk structures* and *context structures* which serve for spatial orientation can be efficiently segmented.

2. RELATED WORK

While preoperative segmentation of relevant structures is a frequent task in general, we are not aware of any dedicated effort to support neck dissection planning with appropriate segmentation methods.

There are a few research reports on the segmentation of lymph nodes. Honea et al.[2,3] used an Active Contour in 2D and 3D to find closed contours. The applicability of the method is restricted to structures with strong gradients. Yan et al.[4] introduced an enhanced fast marching approach (in 2D). The problem of over-segmentation of this method could be solved only by placing user-defined barriers with high user interaction effort.

3. SEGMENTATION TECHNIQUES FOR NECK CT DATA

We tested the appropriateness of simple segmentation methods (threshold, region-growing, interactive watershed transformation and live-wire) for the neck structures to be segmented. The focus of our development is on minimizing the required interaction effort, the accuracy of the segmentation results as well as on the time needed for segmentation. Furthermore, the ability for automation of these methods was investigated.

3.1. Datasets

For analyzing the appropriateness of segmentation methods, 12 CT and 4 MRI neck datasets were available. 13 of these datasets contained a tumor in the neck region, with suspicion of neck lymph node metastases.
The quality of the datasets varied significantly: The slice distance of the datasets, depending on the structures to be examined, varied between 0.7 to 5mm. For the detection of small structures (e.g. the lymph nodes) low slice distances are necessary. Some of the datasets bore artifacts (e.g. motion artifacts) and noise or very low contrast which makes detection and segmentation of the neck structures difficult. In general, image analysis is extremely laborious in case of MRI data because of the inhomogeneity. Due to the lower spatial resolution 3D visualizations of smaller anatomic structures cannot be generated. Therefore, we rejected MRI data for our study.

3.2. Segmentation Methods

The appearance of neck structures in the CT data is strongly different from patient to patient. There are differences in their range of hounsfield units, their shape, and their relation to adjacent structures (gray values and the existing gradients). Thus, there are different methods for segmentation necessary. For this purpose, we evaluated and adapted the following elementary existing segmentation techniques. They were investigated in order of increasing degree of interaction.

1. Automatic *threshold*, no user interaction is necessary.
2. Conventional *region growing*, a threshold-based method with user-defined starting points.
3. *Interactive, marker-based watershed transformation* based on gray value images.[5] Several "include" and "exclude" markers have to be placed by the user.
4. *Live-wire*, a 2D semiautomatic, edge-based method (supported contour tracing), which can be interpolated between the CT slices.[6] The user has to draw contours semi-automatically in approximately every fourth slice.

An appropriate method to segment air-filled structures is a *threshold* with a succeeding analysis of the connected components (CCA) to separate trachea, pharynx, and lungs. User interaction (placing one marker) is needed to specify the glottis, which separates the pharynx from trachea. After the CCA the resulting components are analyzed: The two objects where the maximum z-value is the lower than the glottis markers z-value (z values correspond to slice numbers) are regarded as the lungs. The object containing the marker in the glottis is identified as the pharynx-trachea tube. It is divided at the marker in two objects. The remaining components are irrelevant and are discarded. The method obviously fails if the trachea and one of the lungs belong to one component.

We do not employ threshold-based segmentation for bones since in contrast-enhanced images the blood vessels exhibit the same gray values as bones and therefore vessels and bones cannot be discriminated based on a threshold.

Region growing is a fast and satisfactory method for segmentation of bony structures, such as the mandible, clavicle and vertebrae. In cases where not all bones are connected to each other, there are up to 15 markers necessary for a complete segmentation. In contrast-enhanced datasets, it is required to segment the vessels prior to the bones and remove them from the dataset (as mentioned above).

For pre-operative planning of neck dissections, only the main stems of relevant blood vessels (V. jugularis, A. carotis) are important. With region growing, these vessels could not be segmented as separate branches because they are all connected to each other.

The segmentation with the *interactive watershed transformation*[5] is employed for extracting the vessels. Contrary to the region growing, it is possible to segment separate branches. Major branches can be easily separated from minor ones or other connected blood vessels by placing "exclude" markers. The segmentation of vessels without contrast agent is more complex because of the lower contrast to the surrounding soft tissue. There were up to 130 markers necessary to get a good result.

As expected, region growing turned out to be not appropriate at all for the soft tissue structures, the larynx, the tumor and the lymph nodes, because the segmentation leaks to the surrounding structures with similar gray values. The watershed transformation is like region growing not appropriate to segment the soft tissue structures, the larynx, the tumor and the lymph nodes.

For these cases, *live wire* provides a more manageable method with better results. The contours have to be drawn by the user on every fourth or fifth slice. The contours in intermediate slices are interpolated (with a subsequent automatic live-wire optimization).[6] Live-wire is an acceptable method for structures, even though the differences in gray values of adjacent tissues are minimal. On those edges, it is necessary to "learn" from the current contour. "Learning" means to derive the parameters of the cost function, such as mean and variance of the gray value, from the current contour. Live-wire does not work in the same quality for all structures. Especially in the case of low contrast regions more user interaction is needed.
Regarding the expenditure of time and the accuracy of the results for lymph node segmentation with live wire it is in our opinion more useful to draw contours from the relatively small and compact lymph nodes and tumors manually and use interpolation as well.

The relation of enlarged lymph nodes to nerves is crucial for neck dissection planning, since damage to the nerves results in major long-term complications for the patient. It is difficult to detect nerves in CT datasets because of the ratio between resolution of the data and the size of the nerves. Therefore, the user places markers in the visible parts of the nerves. These markers are interpolated to line strips which approximate the location of the nerves in the neck. This appropriate visualization is motivated by anatomic knowledge (nerves in the facial regions are usually not strongly bended). Our co-operation partners evaluated this as a sufficient method to estimate if nerves are at risk. Figure 2 shows a visualization of the markers and the interpolated line strip to approximate a nerve. This visualization is designed such that the uncertainty of the precise course is conveyed.

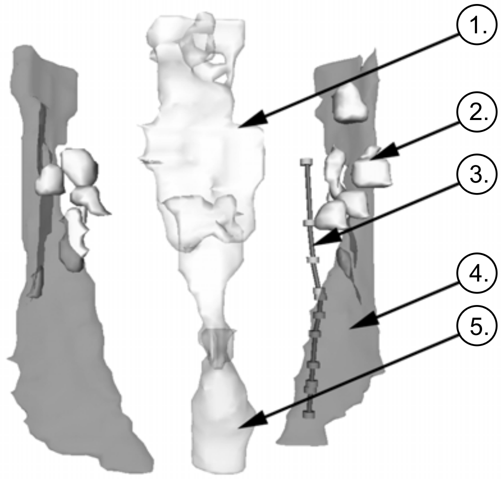


Figure 2. 3D visualization of segmented neck structures (1) pharynx, 2) lymph node, 3) N. vagus left, 4) M. sternocleidomastoideus, 5) trachea). For the N. vagus user-defined markers (cylinders) are interpolated to a line strip.

4. DESIGN AND IMPLEMENTATION OF NECKVISION

The tested segmentation techniques which turned out to be appropriate were optimized and integrated into the software assistant NeckVision. The basis for the implementation was the image-analysis and visualization platform MeVisLab (www.mevislab.de). Similar to other image analysis platforms, MeVisLab follows a visual programming approach where the image analysis (e.g. preprocessing, segmentation) and visualization moduls (e.g. surface and volume rendering) can be visually combined to form complex networks.[7]
There have been three main demands for the design of NeckVision:

1. The design of NeckVision should be interactively and intuitively usable for clinicians.
2. The order of processing steps of NeckVision should support the users workflow and facilitate segmentation.
3. NeckVision should possess a modular structure to replace the applied algorithms for the segmentation of each neck structure easily as soon as better methods are available.

The design of the user interface was inspired by related systems in the clinical routine and other software assistants developed with MeVisLab.[8] This should enhance the acceptance and facilitate the use for the clinical partners. The neck dataset and results (together with segmentation parameters) are managed in an "xml"-file. This enables the user to reload results and carry out changes later on.

The order of segmentation steps (see Figure 3) is first of all relevant with respect to the clinical problem and second with respect to the algorithms. The basic concept for segmentation is to extract certain and easy structures first. This knowledge is used to segment more difficult structures.

With respect to the clinical problem it is useful to segment the tumor or metastases in the first segmentation step (step 2). Thus the user gets a survey of the specific position of the tumor and its surrounding structures. As an alternative, it is also reasonable to extract the lymph nodes during the first step because they are as important as the tumor for neck dissections. However, their detection and extraction is not easy and should be (semi)automatic. Therefore it is necessary to employ knowledge about the other neck structures and segment these structures prior to the lymph nodes.

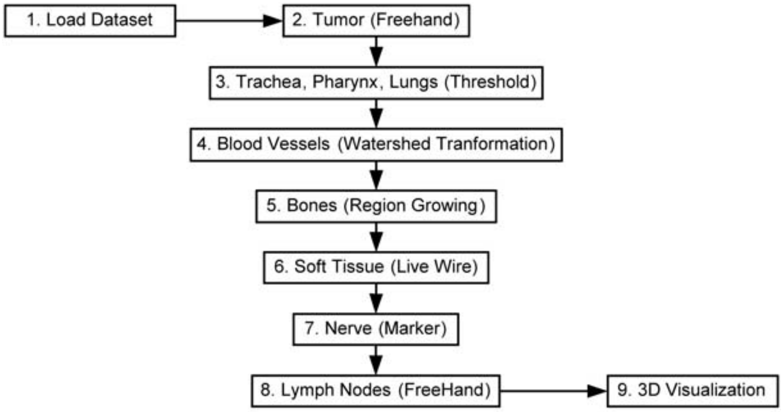
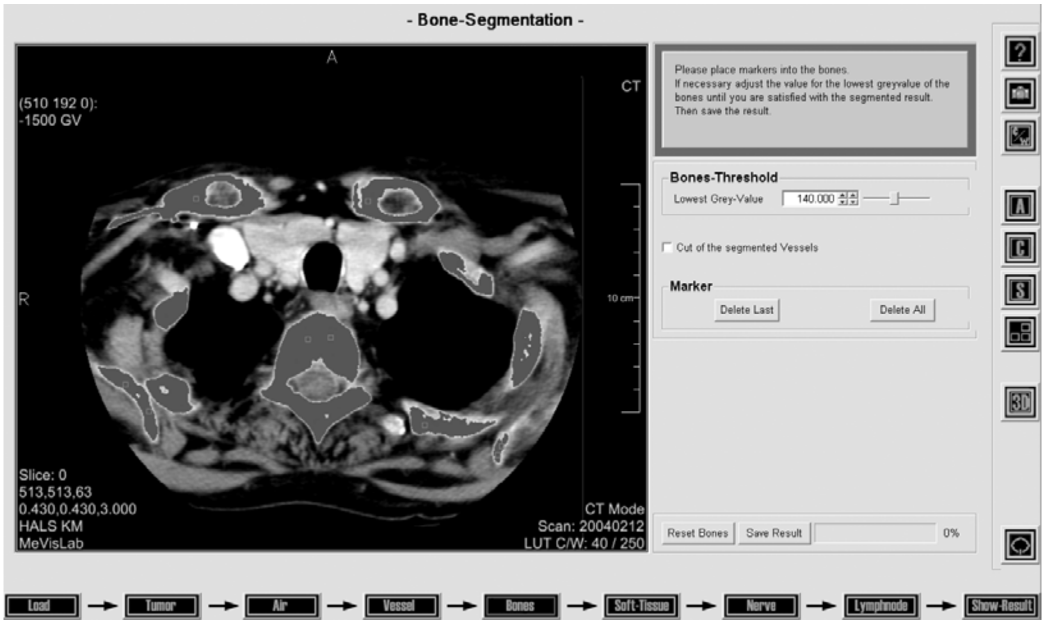


Figure 3. Workflow for the segmentation of the neck CT datasets with NeckVision. The segmentation method is indicated in parentheses.

The following steps relate to the segmentation of structures which can be efficiently performed with simple algorithms. The results achieved in these steps are the basis for the more complex methods following in the segmentation process afterwards. The second processing step includes the segmentation of the air-filled structures by a threshold and a following component analysis (step 3). After that the blood vessels are to be extracted with a watershed transformation (step 4).

Segmentation of the bones (step 5) is carried out after the segmentation of the blood vessels (see Figure 4). In the next two steps, soft tissue and the larynx structures are extracted with live wire (step 6) and the nerves are defined by placing markers (step 7). In a final segmentation step, the lymph nodes are segmented, currently still by manual drawing of the contours (step 8). This pre-defined but not binding sequence of working steps supports the user's workflow. He can deviate from the recommended workflow but vessels should be segmented before bones and lymph nodes at the last step. After segmenting all relevant structures, tumor, and lymph nodes the results can be surveyed in the last step of NeckVision two-dimensionally as overlays in the CT slices and in a 3D visualization (step 9). The 3D visualization should only be a rapid inspection for the users to check the visual plausibility of results. In this last step of NeckVision the structures can be turned on and off and changed in their transparency to give the user the possibility to examine the results separately and in their context. It is also possible to measure minimal distances, main axis, and volumes (see Figure 5 right). This simple visualization does not replace surgery planning.

To enhance the acceptance in clinical routine, the algorithms that have been used so far are to be replaced by some automatic or semi-automatic techniques. These techniques are currently being developed and shall be integrated as soon as they produce reliable results. A more automated method for segmentation of lymph nodes has been developed in *Seim*.[9] As soon as this method is evaluated more thoroughly, the manual segmentation will be replaced.



Please place markers into the bones.
If necessary adjust the value for the lowest greyvalue of the bones until you are satisfied with the segmented result.
Then save the result.

Lowest Grey-Value: 140.000

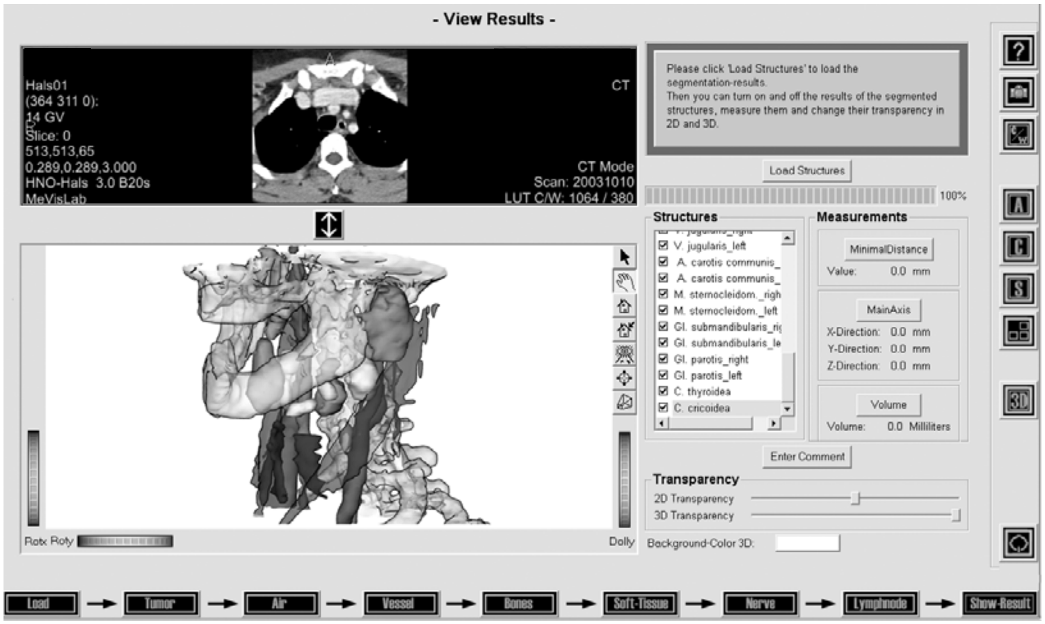
☐ Cut of the segmented Vessels

(510 192 0):
-1500 GV

Slice: 0
513,513,63
0.430,0.430,3.000
HALS KM
MeVisLab

CT Mode
Scan: 20040212
LUT C/W: 40 / 250

Figure 4. The step of bone segmentation of NeckVision. Bones are segmented with region growing by placing markers.



Please click 'Load Structures' to load the segmentation-results.
Then you can turn on and off the results of the segmented structures, measure them and change their transparency in 2D and 3D.

- ☑ V. jugularis_left
- ☑ A. carotis communis_
- ☑ A. carotis communis_
- ☑ M. sternocleidom._righ
- ☑ M. sternocleidom._left
- ☑ Gl. submandibularis_ri
- ☑ Gl. submandibularis_le
- ☑ Gl. parotis_right
- ☑ Gl. parotis_left
- ☑ C. thyroidea
- ☑ C. cricoidea

Value: 0.0 mm

X-Direction: 0.0 mm
Y-Direction: 0.0 mm
Z-Direction: 0.0 mm

Volume: 0.0 Milliliters

2D Transparency
3D Transparency
Background-Color 3D:

Figure 5. The "ShowResult" step of NeckVision. The structures selected on the right are included in the visualization using default colors and transparency.

5. EVALUATION

The prototype of NeckVision was evaluated in a (small) empirical evaluation with four otorhinolaryngologists from the university hospital of Leipzig, four computer scientists from the university of Magdeburg and two laymen in both fields.

5.1. Datasets

For this test, two different CT datasets, with a slice distance of 3mm and a slice thickness of 3mm, were selected and the structures which should be segmented by the test persons were determined (tumor, lymph nodes, trachea, pharynx, lungs, V. jugularis right, bones, M. sternocleidomastoideus right, Gl. submandibularis right, one nerve visible in the data). For the more complex steps, one or two structures were selected and for the other steps several (2-5) structures.

5.2. Realization of the Test

The test design considered that the duration is limited to an hour. To eliminate the dependency of the test results from only one dataset, two groups (each consisting of 5 test persons) were formed. Each of them segmented one dataset. Before they started working, they were given an introduction in NeckVision and its functionality on the basis of an example segmentation. After that there was time (about 30 minutes) for the test persons to familiarize themselves with the system. The actions during the segmentation process and the time needed for each step were recorded to detect which controls were not used, which functions are apparently ambiguous to the user, or which segmentation steps are time-consuming.

A statistical analysis of the results, e.g. the segmentation time for the structures, is not reasonable due to the low number of test persons. However, general conclusions concerning the usability can be made. After segmenting with NeckVision the test persons filled out a questionnaire. It contains questions related to their profession, their experience with computers and to different aspects of the segmentation assistant. Users were asked to assess NeckVision concerning the interface, terminology, feedback, waiting time, learnability, and failure frequency.

5.3. Analysis of the Test Results

The analysis of the completed questionnaires revealed that the test persons evaluated the application in the majority of the assessed aspects as good and better. In addition to the user study, we compared the segmentation times for the neck structures without NeckVision and with support of our software assistant. Without NeckVision, the user has to open each MeVisLab network for the segmentation algorithms and several modules (e.g. for loading the dataset, for segmentation, for saving the results) manually. Furthermore, the user has to perform the management of the segmentation results and has to start the generating of the 3D models for each structure.

This comparison is not as accurate as desired because the available data for the test persons of the usability test (with 2 datasets) were compared to the times of segmentation without the software assistant from one user and 16 datasets. The times for neck structures which were segmented in both test groups and the times for segmentation without NeckVision have been extrapolated to get a consistent number of structures (see Figure 6 for used structures and times).
Segmentation times depend on the quality of the data and on the time needed for detecting the structures. These times differ especially for the lymph nodes and are sometimes very high. No statistical conclusions could be made, but a trend was obvious.

On average for segmentation with NeckVision less time is needed. The actions of loading the dataset for every new segmentation step with a different method are not required and the results are saved and named automatically. When saving one result, the segmentation is deleted on the slices so that the user can immediately start with the next segmentation step (according to presented workflow). Without NeckVision, performing the management of the segmentation results manually is time-consuming and annoying. Furthermore, default values in NeckVision for each parameter (e.g. thresholds) facilitate segmentation and save time. Especially times of steps where several structures are to be segmented (like blood vessels, muscles/glands and lymph nodes) differ strongly because of the above-described reasons. Time for extracting the bones is higher for segmentation without NeckVision because the possibility to remove the already segmented blood vessels does not exist and determination of the threshold gets more difficult.

This user study should provide feedback regarding the usability of the first prototype. It resulted in minor improvements of the user interface. The workflow and the general layout of NeckVision were confirmed. According to proposals of several users, feedback was improved for example by adding progress bars.
An enhanced version of NeckVision is planned to be evaluated in future in a larger study.

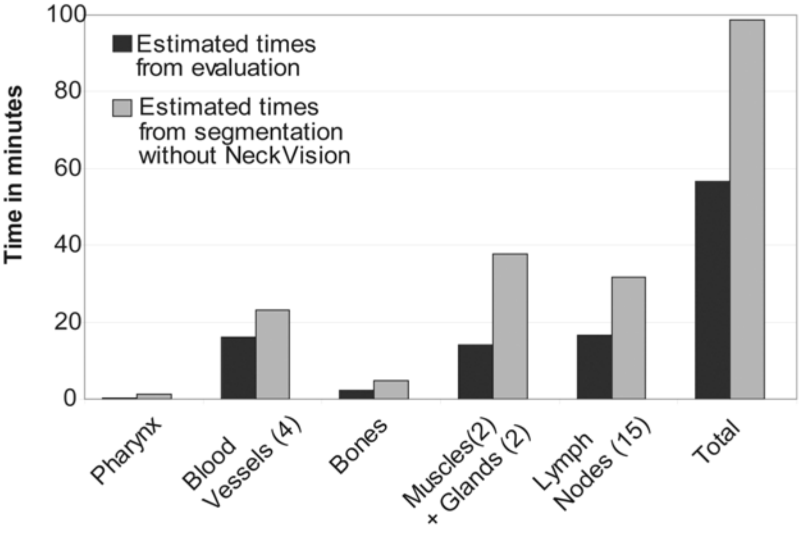
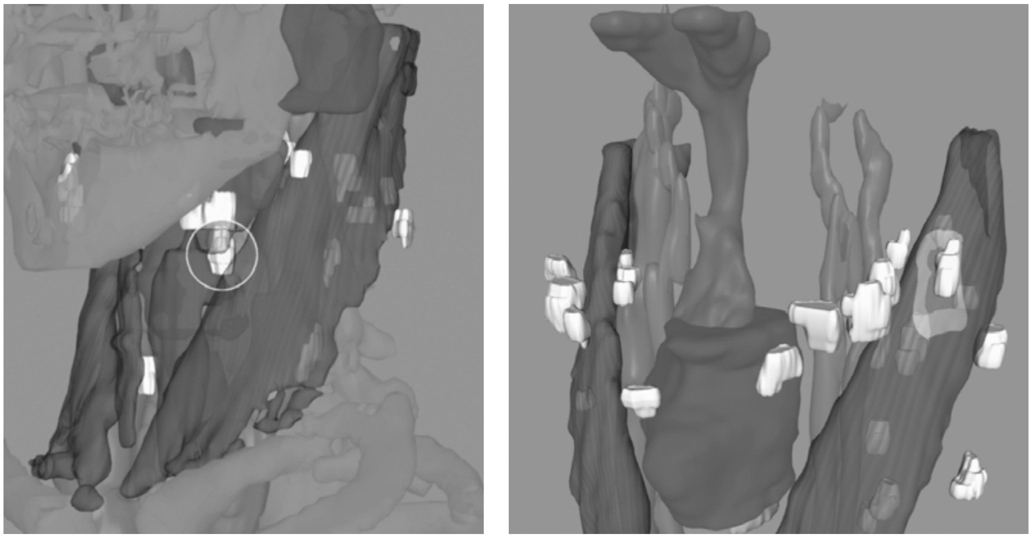


Figure 6. Comparison of segmentation times with and without NeckVision.



(a)

(b)

Figure 7. Examples for visualization techniques for neck structures. Color and transparency for context structures are chosen such that the lymph nodes can be recognized. Vertically striped opacity mapping is employed for muscles to illustrate the fibers and make lymph nodes visible which are located behind. (a) Accentuation of a lymph node by a ghost view. (b) Color-coded distance of lymph node and muscle.

6. DISCUSSION

The quality of the segmentation results was regarded as satisfactory and better by ENT surgeons. NeckVision was installed at the university hospital Leipzig. To achieve a more regular clinical use, the time and interaction effort for the soft tissue and blood vessel segmentation must be reduced significantly. The goal is to demand not more than 10 minutes of interaction from the user. After that, only automatic calculations may still take place. For this goal of further automation, the use of model-based segmentation techniques seems essential. For example, the segmentation of the blood vessels and long muscles might be significantly improved this way. The same is true for the segmentation of the lymph nodes, which will in future work be addressed by a 3D deformable model.

A detailed discussion of visualization options for neck dissection planning is given in *Krueger et al.*[10] Transparency, silhouettes and color-codes distances as well as opacity-mapping and ghost views are used for visualization of the neck structures segmented with NeckVision. Although, our work has been focused on the analysis of CT data so far, in the future MRI might be a viable alternative. Recent developments in MR imaging allow to decrease the slice distance without an increased signal-to-noise ratio.

ACKNOWLEDGMENTS

This work was carried out in the framework of a project supported by the Deutsche Forschungsgemeinschaft (DFG) (Priority Program 1124, PR 660/3-1). Special thanks go to the physicians and other test persons of the evaluation.

REFERENCES

1. "German Cancer Research Institute." http://www.dkfz.de/. recalled on 01.April 2005.
2. D. Honea, Y. Ge, W. E. Snyder, P. F. Hemler, and D. Vining, "Lymph-Node Segmentation Using Active Contours," in *Medical Imaging Proc. SPIE*, **3034**, pp. 265–273, 1997.
3. D. Honea and W. E. Snyder, "Three-Dimensional Active Surface Approach to Lymph Node Segmentation," in *Medical Imaging Proc. SPIE*, **3661**, pp. 1003–1011, 1999.
4. J. Yan, T. Zhuang, B. Zhao, and L. H. Schwartz, "Lymph Node Segmentation from CT Images Using Fast Farching Method," in *Computerized Medical Imaging and Graphics*, **28**, pp. 33–38, 2004.
5. H. Hahn and H.-O. Peitgen, "The Skull Stripping Problem in MRI Solved by a Single 3D Watershed Transform," in *Medical Image Computing and Computer-Assisted Intervention (MICCAI)*, **1935 of LNCS**, pp. 134–143, Springer, 2000.
6. A. Schenk, G. Prause, and H.-O. Peitgen, "Efficient Semiautomatic Segmentation of 3D Objects in Medical Images," in *Medical Image Computing and Computer-Assisted Intervention (MICCAI)*, **1935 of LNCS**, pp. 186–195, Springer, 2000.
7. H. Hahn, F. Link, and H.-O. Peitgen, "Concepts for Rapid Application Prototyping in Medical Image Analysis and Visualization," in *Proc. Simulation und Visualisierung 2003, Magdeburg, Germany*, pp. 283–298, 2003.
8. H. Bourquain, A. Schenk, F. Link, B. Preim, G. Prause, and H.-O. Peitgen, "HepaVision2: A Software Assistant for Preoperative Planning in Living-Related Liver Transplantation and Oncologic Liver Surgery," in *Computer Assisted Radiology and Surgery (CARS 2002)*, H. U. Lemke, ed., pp. 341–346, 2002.
9. H. Seim, "Modellbasierte Segmentierung von Lymphknoten in CT-Daten des Halses," Master's thesis, Otto-von-Guericke-Universitaet Magdeburg, 2005.
10. A. Krueger, C. Tietjen, J. Hintze, B. Preim, I. Hertel, and G. Strau, "Interactive Visualization for Neck Dissection Planning," in *IEEE/Eurographics Symposium on Visualization (EuroVis)*, pp. 295–302, 2005.