Analysis and Exploration of 3d Visualization for Neck-Dissection Planning

Arno Krüger [a] Christian Tietjen [a] Jana Hintze [a] Bernhard Preim [a] Ilka Hertel [b]
Gero Strauß [b]

[a] *Department of Simulation and Graphics, Otto-von-Guericke-University of Magdeburg, Germany*
[b] *ENT Department, University Hospital of Leipzig, Germany*

Abstract

We present visualization techniques for neck dissection planning. These interventions are carried out to remove lymph node metastasis in the neck region. In 18 CT-datasets, the relevant anatomic and pathologic structures were segmented. 3d visualization is intended to explore and to quantify anatomic and pathologic structures and thus support decisions concerning the surgical strategy. For this purpose we developed and combined visualization and interaction techniques such as cutaway views, silhouettes and color-coded distances. In addition, a standardized procedure for processing and visualization of the patient data is presented.

Key words: medical visualization, neck dissection, operation planning, lymph node exploration

1. Introduction

Neck dissections are carried out for patients with malignant tumors in the head and neck region. These surgical procedures are necessary because the majority of the patients develops lymph node metastases in the neck region. The extent of the intervention depends on the occurrence and location of enlarged (and probably) malignant lesions. In particular, the infiltration of a large muscle (*M. sternocleidomastoideus*), a nerve (*N. facialis*) or blood vessel determine the surgical strategy. The identification and the quantitative analysis of lymph nodes with respect to size and shape is crucial for the surgeon's decision. The image analysis and visualization techniques described in this paper support decisions regarding the resectability and the surgical strategy for neck dissections. Visualization techniques aim at comprehensible renderings of the relevant information. This includes the visualization of the target structures and some context information necessary to illustrate the spatial relations. By means of our visualizations, we convey information concerning critical distances or even infiltrations of lymph nodes into important structures. In addition to carefully parameterizing surface rendering, we explore silhouette rendering and cutaway views for parts of an object's surface. We also discuss interaction facilities to explore the data. In particular, we discuss the selection of lymph nodes based on their properties.

Preprint submitted to Elsevier Science *10 March 2005*

2. Image Analysis

The segmentation of the relevant anatomic and pathologic structures is a prerequisite for the selective visualization and the quantitative analysis of the patient data. For surgical planning, the extent of pathologic structures, distances to important anatomic structures and the potential infiltration are of special interest.

We employed 18 CT-datasets which have been acquired for neck dissection planning. Twelve of these datasets contained a tumor in the head and neck region and were suspected of containing lymph node metastases as well. We choose not to employ MRI data, although they are wide-spread for diagnosis in the neck region due to their inherent inhomogeneity and low resolution. The quality of the datasets was diverse with respect to the signal-to-noise ratio, motion artifacts as well as the slice distance (0.7 to 3 mm), resulting from different CT scanning devices and acquisition parameter. The data were exchanged based on a WWW upload including information concerning the diagnosis of the patient and specific requirements for computer-supported planning.

Segmentation was carried out by means of MeVisLab, a library which provides a variety of image processing and segmentation methods (MeVis, Bremen, http://www.mevislab.de). The following target structures of the segmentation were identified as being most relevant for preoperative planning: vascular structures (*V. jugularis, A. carotis*), muscles (*M. sternocleidomastoideus*), skeletal structures (*Mandible* and *Clavicle*), *Gl. submandibularis* and *Gl. parotidea*, *Pharynx*, *N. accessorius*, primary tumor, lymph nodes, with emphasis on enlarged and potentially malignant nodes. In selected cases, the segmentation of additional structures is desirable, e.g. additional muscles or nerves.

A live wire approach was employed for the segmentation of muscles (*M. sternocleidomastoideus, M. omohyoideus*) and the salivary glands. The interactive watershed transform [1] proved to be suitable to identify and delineate the *V. jugularis* and *A. carotis*. Intensity-based region growing was used for bone and *Pharynx* segmentation. While the muscles and the glands could be identified in the majority of the datasets, most of the desired nerves could not be identified due to their size in relation to the image resolution. Among the vascular structures, only the *A. carotis* and *V. jugularis* could be segmented in most of the data.

Nerves are very difficult to detect in CT-images because they are very small. Only in CT-data with 1 mm slice distance, the *N. accessorius* and *N. vagus* could be identified manually in a few slices. Even in these datasets, only a partial segmentation is feasible, because their size and contrast is too small. As the approximate course of these nerves is essential for surgeons, we chose to segment them partially for an approximate visualization (see Figure 1 (left)).

Primary tumors were segmented manually. They exhibited low contrasts and could only be distinguished by exploiting considerable anatomic knowledge, in particular symmetry considerations. At present, also the lymph nodes are identified manually. The segmentation is described in more detail in [2].

3. Visualization of the Segmented Target Structures

We discarded volume rendering because it does not provide essential information for our purposes. By relying on surface visualizations, we provide all necessary information within rather small surface models which can be easily transmitted over the internet and explored using wide-spread software.

Our color selection was guided by observations from textbooks and later refined in discussions with the clinical partners. Transparency was primarily used to expose important structures, such as lymph nodes. In several in-depth discussions, we modified colors and transparencies for all structures to enhance contrasts and recognizability of object borders.

It turned out that object-based transparency specification does not allow a comprehensible visualization of complex structures. With multiple highly transparent objects, the specific location of a target object is barely visible with a high opacity on the other hand, the spatial relations between emphasized objects are difficult to recognize. As a solution we employ object-based opacity maps with alternating opaque and semi-transparent stripes. They are mapped to the neck muscles in roughly the same direction as real fibers. We calculate the enclosing cylinder of a muscle and use this cylinder to define the opacity map. With this technique the texturing of the neck muscles is slightly indicated.

To improve the visibility of lymph nodes and tumors, all colors from other objects are reduced in saturation and lightness. Especially skeletal structures are invisible during surgery and provide only spatial orientation, e.g. *Mandible* and *Clavicle* serve as landmarks. In Figure 1 (right), the improved color selection for lymph node emphasis is shown.

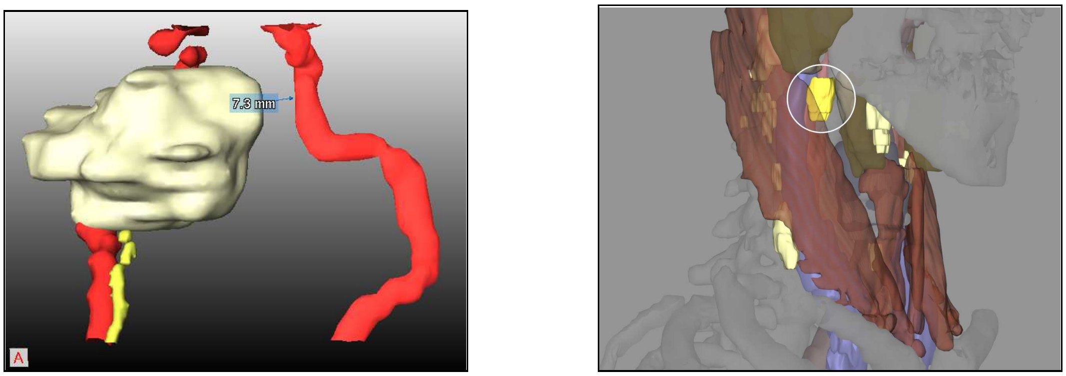

Fig. 1. Left: *N. hypoglossus* (yellow) and *A. jugularis* (red). Notice the slice artifacts in the course of the nerve near the tumor (dark yellow). Right: Emphasized lymph node partially behind the *M. sternocleidomastoideus* with the use of a cutaway view as well as thin silhouette lines.

Measurement tools to compute the extent of anatomic structures and the distance between structures are also provided [3]. With these tools, the extent of enlarged lymph nodes can be determined precisely. The measurements are directly included in the 3d visualization.

4. Interaction Techniques for Exploring Lymph Nodes

The exploration of a complex set of enlarged and therefore surgically relevant lymph nodes requires appropriate interaction techniques. The usual selection of objects via their name is not feasible. The selection of entire lymph node groups or via measurement results is more appropriate. Extent or minimal distances to risk structures are possible criteria.

The basic interaction for the exploration of lymph nodes is the selection with appropriate feedback. We suggest a facility to step through all lymph nodes with a simple interaction. We found that the most interesting information are the number of enlarged lymph nodes and their potential malignity. Therefore, a simple list, ordered by the lymph node number, is not appropriate for exploration. In our planning tool we provide two different selection criteria - extent and volume.

As a feedback after selection, lymph nodes should become visible. It is not appropriate to render a large object, such as the *M. sternocleidomastoideus*, highly transparent, to expose a small lymph node. A better alternative is to render only a small part of the muscle transparent which can be achieved by cutaway views (see [4]). We use a cylindrical bounding volume, that is cutting all structures in front of the lymph node. The intersecting parts of foreground objects within the bounding volume are displayed strongly transparent. However, the depth perception is limited in this region. Therefore a thin silhouette (see [5]) of the muscle is included brightly. With these visualization parameters, foreground and background objects are correctly perceived. The emphasized area is additionally marked with a bright circle. The lymph node is visually enhanced by raising the saturation of color (see Figure 1 (right)). This combination of visualization techniques is applicable also for multiple occlusions or full visibility. Hence, the surgeon may interactively step through all lymph nodes, e.g. by pressing the tab key. The currently selected object will always be clearly emphasized.

For the evaluation of the resectability, distances to risk structures are crucial. We employ a distance-dependent coloring of the neck vessels and muscles which conveys the distance to the lymph nodes. With a discrete color scale (gradation: 2 and 5 mm) the resectability of this target may be evaluated. The emphasized lymph node in Figure 2 (left) is located in front of the *M. sternocleidomastoideus*, where the distance information is displayed.

A color-coding of the distances does not indicate an infiltration of a muscle or a vessel. We employ a line character accentuation (see [5]) of the cut line which is marked above the illustration. In Figure 2 (right), the potential infiltration of the *M. sternocleidomastoideus* is shown. According to the segmentation results, these lymph nodes reach into the muscle. In reality it is possible, that the muscle tissue is displaced, but not infiltrated. Distance-related visualizations may be generated for each anatomic structure. Other relevant examples are the *A. carotis* and the *V. jugularis*. A color-coded view for potentially infiltrating lymph nodes is also provided for a fast overview.

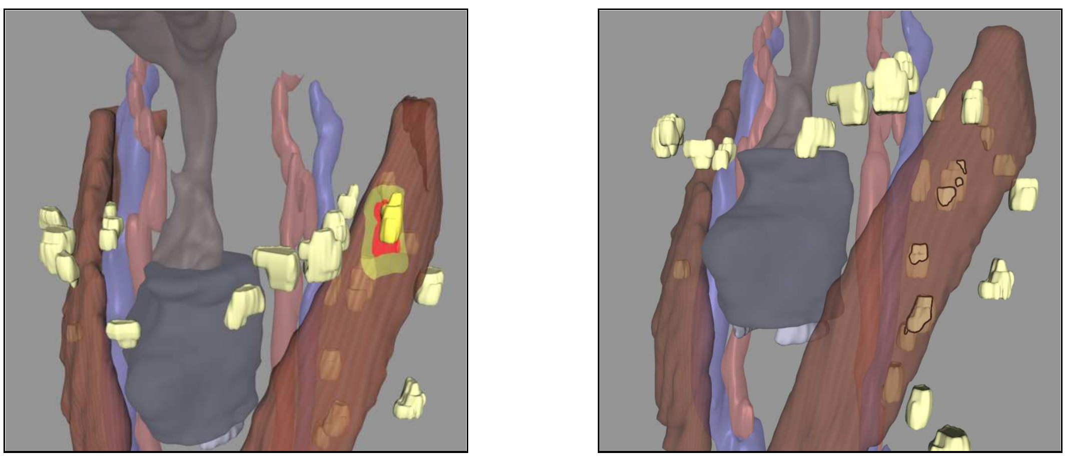

Fig. 2. Left: Color-coded distance of a lymph node to the *M. sternocleidomastoideus*. The 2 mm distance is coded in red, 5 mm in yellow. Right: Possible infiltration of the *M. sternocleidomastoideus*. Silhouette lines form an intersection line between muscle and lymph nodes.

Primarily, the size of lymph nodes is important. Medical doctors consider lymph nodes with an extent of more than 1 cm as potentially malignant and would resect them. Therefore, we generate an initial visualization which conveys the size of lymph nodes. Here, we emphasize lymph nodes larger than 1 cm minus the slice thickness, to account for possible inaccuracies from image acquisition and segmentation.

This visualization is based on data known from the segmentation process. All lymph nodes and tumors are measured automatically by a principal component analysis from which the extent is derived [3]. We do not calculate the volumes of lymph nodes since high measurement inaccuracies due to very small volumes are to be expected.

By a mouse-over interaction, tooltips, respectively text boxes, fade in with the precise measurement values of extent and minimal distances to risk structures. For primary tumors the same interaction is provided. More detailed discussions to the used interaction techniques are described in [6].

5. Standardized Visualization Process and Influence on Surgical Strategies

It was a major goal to produce comparable visualizations for different patient data. Besides the visualization, a procedure for the treatment of datasets is to be defined. This includes the type and resolution of the datasets, the application of segmentation methods, the type of visualization and the presentation of the results. The visualization is carried out as a service for the surgical partner in the framework of a research project. Patient datasets are always submitted with an "order sheet". By this, the diagnosis is stated and target structures besides the standard are listed (recall Section 2).

The segmentation process is also standardized (sequence of segmentation tasks). However, parameters have to be adapted to each dataset. The results are presented as images and animation sequences. 2d-slice views with the segmentation results (which are radiologically evaluated) transparently overlaid to the original data were created to support the verification of segmentation results. Selective clipping of bony structures was used to enhance the interpretation of the spatial relations (see Figure 3 (left)). All results are available for the project partner via a secured web page. The average time for image analysis and creation of the visualizations was approximately 90 minutes. Most of the time was spent on the segmentation of lymph nodes.

It turned out that most of the available video player software is not very useful for therapy planning. Therefore we developed a specialized player called "Medical Movie Player". Here the surgeon can adjust the playing-speed, zoom into the video, step frame by frame forward and backward and make a snapshot (to the clipboard or a file). Fast access to all frames of the clip is also provided and the graphical user interface is optimized for intuitive use (see Figure 3 (left)).

The visualization results were compared with the experiences of real surgical interventions. The surgeons confirmed a high degree of correspondence to intraoperative views. In some cases, the results of computer assisted planning were essential for the surgical decision. For the surgeon it is necessary to evaluate distances to risk structures. The number of lymph nodes is employed to develop an understanding of the expected difficulty of the resection. The above-mentioned information improves neck dissections with respect to speed and safety. In contrast, other information a priori can lead to another surgical strategy. If it turns out, that possibly important structures are infiltrated, the involved areas are not resectable, without previous radiation therapy. Therefore, it is important to estimate the resectability as reliably as possible and to choose the right surgical strategy preoperatively.

Figure 3 (right) shows a case with a large *Hypopharynx* tumor and cervical lymph node metastasis. Operation planning here was especially motivated by knowing the exact size, distance to risk structures and the location of the primary tumor.

6. Conclusion & Future Work

We presented image analysis and visualization techniques for planning neck dissections. The focus of our work is the visualization of enlarged lymph nodes and the surrounding structures. Based on the image analysis results, surgeons are provided with standardized static visualizations and with standardized animation sequences, primarily rotations of different subsets of the target structures. We attempted a standardized report consisting of images from standardized viewing directions. The potential of 3d visualizations for surgery planning cannot be fully exploited by means of standardization. Each and every case exhibits some peculiarities which require interaction techniques to explore them.

Our work is directed at a progress in planning neck dissections; more reliable preoperative decisions and more safety during the intervention are the primary goals. Our strategies to adjust 3d visualizations, to explore spatial relations, is applicable to other areas of computer assisted surgery. The use of silhouettes as well as the use of cutaway views to expose hidden pathologic structures turned out to be useful for surgery planning. Future work includes in-depth user study to characterize the impact of 3d visualization on the surgical strategy.

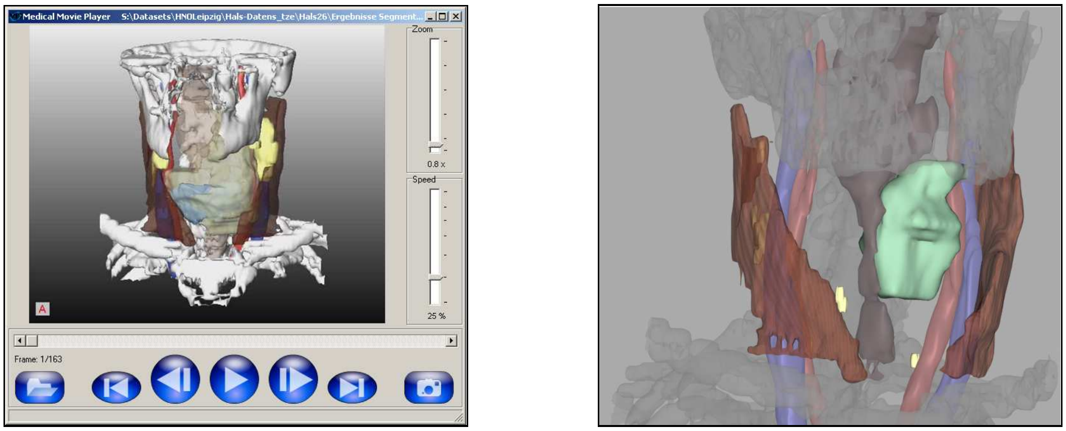

Fig. 3. Left: Main window of the specialized video player "Medical Movie Player". Right: A large tumor (green) infiltrates the *Pharynx*.

Acknowledgments: This work was supported by the Deutsche Forschungsgemeinschaft (DFG) (Priority Programme 1124, PR 660/3-1). Special thanks go to Jeanette Cordes and Ragnar Bade for substantial support on visualization issues. Dr. Uta Preim validated image analysis results as radiologist.

References

[1] H. Hahn, H.-O. Peitgen, IWT-Interactive Watershed Transform: A hierarchical method for efficient interactive and automated segmentation of multidimensional grayscale images, in: Medical Imaging 2003: Image Processing, Vol. 5032, SPIE, 2003, pp. 643–653.

[2] J. Hintze, J. Cordes, B. Preim, G. Strauss, I. Hertel, U. Preim, Bildanalyse für die präoperative Planung von Neck dissections, in: Bildverarbeitung für die Medizin 2005, Informatik aktuell, Springer, 2005. (to appear)

[3] B. Preim, C. Tietjen, W. Spindler, H.-O. Peitgen, Integration of Measurement Tools in Medical Visualizations, in: Proc. of IEEE Visualization, 2002, pp. 21–28.

[4] J. Diepstraten, D. Weiskopf, T. Ertl, Interactive Cutaway Illustrations, Computer Graphics Forum 22 (3) (2003) 523–532.

[5] C. Tietjen, T. Isenberg, B. Preim, Combining Silhouettes, Surface, and Volume Rendering for Surgery Education and Planning, in: IEEE/Eurographics Symposium on Visualization, Springer, 2005. (to appear)

[6] A. Krüger, C. Tietjen, J. Hintze, B. Preim, I. Hertel, G. Strauß, Interactive Visualization for Neck-Dissection Planning, in: IEEE/Eurographics Symposium on Visualization, Springer, 2005. (to appear)