Clinical Impact of the Tumor Therapy Manager

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Abstract

Visual exploration of CT and MRI datasets in clinical practice is still dominated by slice-based viewing. Volume rendering is now widely available but seen primarily as a tool for a fast overview, and only rarely as a visualization to directly support clinical decisions. Research projects aiming at advanced 3D visualizations, such as smart visibility techniques and illustrative renderings, usually fail to meet clinical demands, since the visualizations are not dedicated to specific diagnostic and treatment planning questions. Moreover, they are unfamiliar to users who need reliable and familiar visualizations as a basis for their crucial decisions. Discussions with clinical practicians reveal that the parameterization of such visualizations is too cumbersome and that resulting visualizations are often too complex.

We describe and discuss long-term experiences on developing, testing, and refining image analysis and visualization techniques for ENT surgery planning based on CT data. While visual quality and a faithful rendition of spatial relations indeed are essential, it turned out to be superior to generate sequences of rather simple 3D visualizations directly supporting specific treatment questions instead of presenting many anatomic structures simultaneously. We report on the actual clinical use of the system and discuss how it changed the surgical planning workflow.

Index Terms: J.3 [Life and Medical Sciences]: Medical information systems—Health;

1 Introduction

Medical visualization aims at a realistic, fast and expressive display of medical image data. Recent trends in research and industrial development are to include more realistic effects, such as illumination, and to improve shape perception, e.g. with boundary enhancement. If applied to patient data, these developments bear a great potential for planning interventions, such as surgery, radiation treatment or catheter-based interventional procedures, e.g. endo-vascular stent placement to treat vascular diseases.

For both surgeons and interventional radiologists, a mental model of the relevant target anatomy, including blood and nerve supply is necessary to prepare an intervention. Intervention planning comprises decisions, such as applicability of an intervention, extent of surgical removal, selection of an appropriate access to the pathology, e.g. a tumor, and exploration of adjacent anatomic structures to evaluate the risk of an intervention. Image analysis and visualization should directly support such decisions, e.g. by analyzing the safety margin around a tumor and highlighting affected structures.

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2 Medical Background

Ear-, Nose-, Throat (ENT) surgery is a demanding medical field since accuracy is often crucial, e.g. in implanting hearing aids, and aesthetic considerations are often relevant. In the following, we focus on neck dissections, a surgical procedure, where malignant tumors and lymph node metastasis are removed if possible. Alternative treatments are radiation treatment planning or chemotherapy. Combinations, where tumors are downsized, e.g. by chemotherapy, to allow a surgical intervention are possible. Whether or not surgery is possible and how extended the surgery should be, are major therapy planning questions affecting both risk of surgery and long term survival. The extent relates to the security margin and to the structures which have to be resected. These lead to more specific questions, e.g. Can the larynx be maintained or at least partially maintained so that the ability to speak is conserved or at least may be re-established with appropriate training? For diagnosis, usually CT slice data are sufficient and appropriate. To support the surgeon's mental model, 3D visualizations of the neck anatomy are an advantage (see Fig. 1).

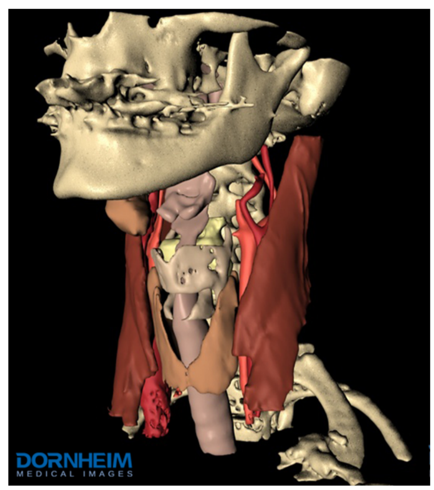

Figure 1: A 3D model of the neck anatomy with bones, muscles, blood vessels and the larynx is derived from CT data of a patient.

3 Project Background

To develop image analysis and visualization algorithms and to integrate them into a dedicated software assistant for the above-mentioned and related questions was the goal of two sequential national research projects, starting in 2004 and lasting five years in total. Research was focussed on automatic segmentation of relevant structures, e.g. lymph nodes [4] and blood vessels [3] and advanced visualization of these structures, e.g. by cut-away views for emphasizing lymph nodes [5] and careful combinations of slice-based and 3D visualizations [6]. In visualization, we first attempted to display as many anatomic structures as possible simultaneously, using silhouettes and opacity mapping to support shape and depth perception. Later, it became obvious, that the resulting visualizations are too complex. Intraoperative visualization was not tackled since, in general, open surgery has lower demands for intraoperative guidance compared to endoscopic and interventional procedures. In contrast to abdominal-, neuro- or heart surgery, the target anatomy in the neck is rather close to the skin. Thus, localization of tumors and relevant risk structures is fairly easy. The operation itself, however, is demanding due to the high density of crucial anatomic structures.

Two research prototypes, NECKVISION for segmentation and the TUMORTHERAPYMANAGER for interactive exploration and documentation were developed and used in clinical practice since 2006. Initial refinements were targeted at improved segmentation (more automatic segmentation methods), modifications of the Graphical User Interface and a direct support for the surgical workflow. The clinical partners started to present these systems first internally, e.g. at the tumorboard, and later at their workshops and conferences leading to additional and generally positive feedback. Based on this feedback, interest from a leading industry supplier, and the continuous support of the clinical partners, a spin-off company, DORNHEIM MEDICAL IMAGES, was founded in early 2008 in order to transform the prototypes in product quality software which is legally admitted to be regularly used as a product of medicine.

4 IN-DEPTH TASK ANALYSIS

As a major prerequisite for developing a practical tool for broad real world use, we entered again in a stage of in-depth task analysis. While in the research project, a trade-off between scientifically interesting questions and real needs was required, a rigorous analysis of tasks, preferences and priorities was necessary for the actual clinical use. This analysis was accomplished as a larger set of interviews at the ENT department in Leipzig as well as observations of clinical processes including surgery. In principle, the same techniques have been used within the research project but in a significantly lower scale. This analysis was focussed on an understanding of:

1. individual surgical planning, particularly preoperative decisions,
2. integration of information derived from radiology data and other examinations,
3. collaborative treatment planning, in particular tumor board discussions,
4. patient consultation, and
5. documentation.

To represent the results, informal scenario descriptions [1] have been created, discussed, refined, and verified by discussing them with the clinical experts. These scenarios describe different clinical cases, all examinations which are accomplished to come to a diagnosis, the planning process and the post-operative situation. Special care was necessary to cover a representative set of different diseases (different with respect to number and size of metastasis, location of metastasis, infiltration of risk structures). A few examples, related to selected issues of the list above, might highlight this process.

Infiltrations. It turned out that infiltrations of anatomic structures by a tumor are investigated in detail with respect to the likelihood of an infiltration, the extent of an infiltration (*Which portion of a vessel cross-section is affected by an infiltration? What is the longitudinal extent of this infiltration?*). Thus dedicated visualizations are desired which contain just the risk structure, the tumor and the possible infiltration area (see Figs. 3 and 4).

Integration of Panendoscopic Findings. Besides CT or MRI data, endoscopic interventions are the most important source for information relevant for surgical decisions. With an endoscope, the surgeon investigates possible tumors, using optical information and touch sense. This information is represented in special sheets of paper, where schematic drawings of the neck anatomy are added with the findings. The task analysis clearly revealed a need for integrating this information with the electronic documentation and the findings from CT data.

Documentation. For medical doctors in general, and for surgeons in particular, a careful documentation of diagnostic information, treatment decisions and patient consultation is essential because of juristic reasons and of the account with social insurance. Such bureaucratic tasks are time-consuming and annoying for the surgeons. Therefore, it turned out that any support which shortens the documentation is highly welcome. Thus, we carefully investigated, e.g. automatic tumor staging, based on measurements applied to all metastasis and also generated automatic visualizations for direct use in the documentation to reveal all relevant findings.

5 TUMORTHERAPYMANAGER

The following images indicate the visualizations actually generated for clinical use and how they are integrated in a clinical workflow. Fig. 2 illustrates how findings from a real endoscopy are combined with a 3D model derived from CT data.

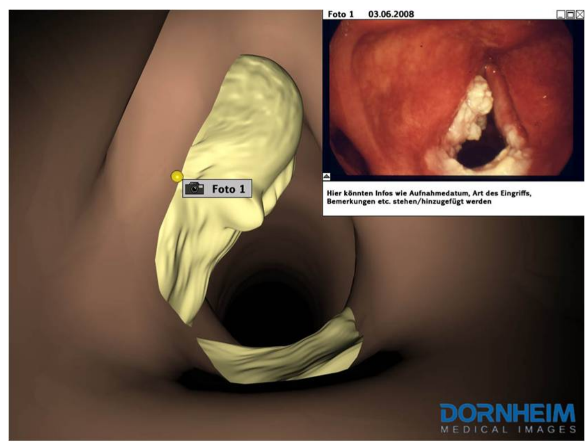

Figure 2: In a virtual endoscopy derived from CT data, a photo of the corresponding real intervention is added at the corresponding position.

Fig. 3 and 4 illustrate how visualizations support the assessment of infiltrations. Such visualizations are part of a step-by-step planning approach where a series of simple visualizations is generated to understand how surgical procedures may affect anatomic structures.

For documentation, a typical sheet of paper is reproduced as an electronic sheet. If possible, all entries are automatically filled in by results from the analysis and the planning process (Fig. 5). The documentation is enhanced with automatically generated screenshots. As an example, Fig. 6 shows, the location of a tumor and its automatically derived measures.

Two screenshots illustrate the current state of the application (Figs. 7 and 8). It is designed to provide an optimum usability but also to provide a good user experience with an attractive layout, comprised of carefully designed visual components. Feedback at various occasions clearly indicated that perceived attractiveness indeed is an important aspect to gain acceptance for a new kind of software support.

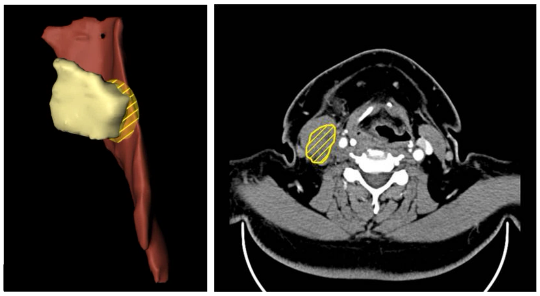

Figure 3: To assess the infiltration of the large Neck Muscle it is shown together with a metastasis and the possible area of infiltration. 3D visualizations and related slices of CT data are combined. The overlay of segmentation information and original image data strongly supports the surgeons.

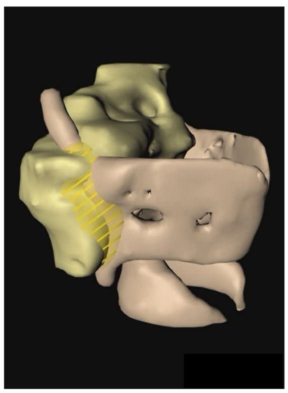

Figure 4: 3D visualization to explore the spatial relations between the larynx and a metastasis. Due to the complex anatomy of the larynx, a 3D visualization is essential. Since the removal of the larynx would have severe consequences, a careful analysis is accomplished to explore whether at least parts of the larynx may be conserved.

TNM-Klassifikation **T1N3M?**

Tumor: T1 T2

Ausdehnung:41x35x19 mm
Volumen 17ml

- Infiltration Schildknorpel

Nodes: N3

Node 1 > 20mm
Node 2 > 18mm
Node 3 > 24mm

- Lymphknotenbefall nur linksseitig

Metastasen (?)

Figure 5: An electronic form is automatically filled in for documentation (currently only in German).

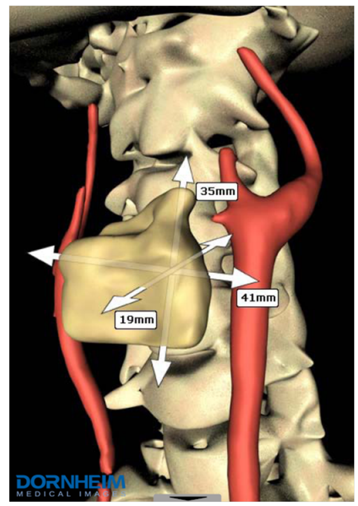

Figure 6: The object-oriented bounding box of a tumor, which represents its extent, is determined and visualized as part of the documentation.

6 Clinical Use of the Tumor Therapy Manager

The TumorTherapyManager has been used for planning approximately 100 neck surgery interventions. In most cases, a selected set of functions was used to segment, quantify, and visualize the tumors in their spatial surrounding. In some 30 cases, the full set of functions – including the virtual endoscopy and the documentation functions were used. The computer-assisted planning process is performed in addition to the conventional planning process based on CT-slices. This is not necessary but serves to compare the different workflows. In approximately 10 cases, the 3D visualizations are employed in the tumor board for interdisciplinary discussions. In general, the surgeon feels safer with the computer-assisted planning and better prepared for surgery. Only, in rare cases however, he changes the surgical strategy with respect to radicality and access.

The computer-assisted planning process is accomplished in difficult cases where the tumor disease is at a later stage and therefore treatment is particularly challenging (two out of three patients exhibit a tumor in the late stages III and IV, and ten percent exhibit metastasis). The system is used in one hospital although care was taken in the task analysis stage that it is not overly specialized for this specific setting.

The TumorTherapyManager is considered particularly useful for planning treatment of surgical interventions at the larynx. This is because all relevant target structures (cricoid cartilage, thyroid cartilage) can be segmented and discriminated well. With respect to tumors in the oropharynx, not all relevant structures can be separated and thus the 3D visualization is less helpful.

Primarily, one surgeon, a co-author of this paper, employs the system and describes that he appreciates particularly, the precise documentation function. This allows for the first time to communicate precisely the findings of the panendoscopy, in particular the estimated depth-infiltration of vascular structures and other tissue (recall Fig. 2). He reports that with these functions he is more careful in the endoscopy since more findings can be reported.

7 Conclusion

Treatment decisions in case of severe diseases, such as cancer or coronary heart disease, is a challenging process where many decisions have to be met with respect to the selected therapies, their combination and sequence. Medical image data plays an essential role in these decisions. Visual computing solutions which provide adequate support based on segmentation, visualization, 3D interaction and workflow support may strongly support such decisions. While state-of-the-art visualization techniques are sufficiently good for the clinical needs, a careful integration of these techniques is needed.

Despite the long-term effort described here, still not all clinical needs are fulfilled in an optimal way. In some hospitals, ultrasound or MRI are primarily used for diagnosis and treatment planning.

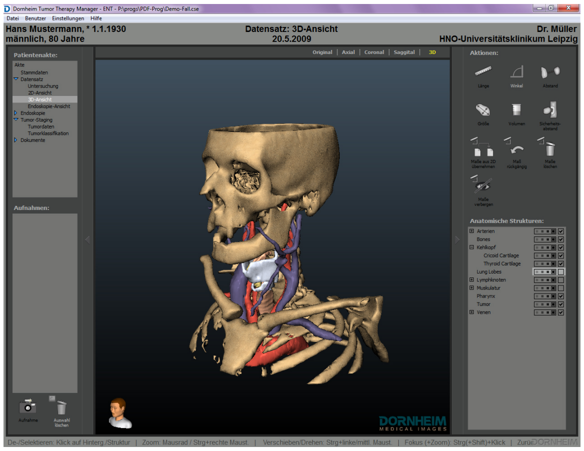

Figure 7: Most of the available space is used for the visualization area, where 2D or 3D visualizations may be displayed. Major tasks, such as tumor staging, are available via the icons on the left side, whereas detailed interactions relating to the visualization are provided in a toolbar (right).

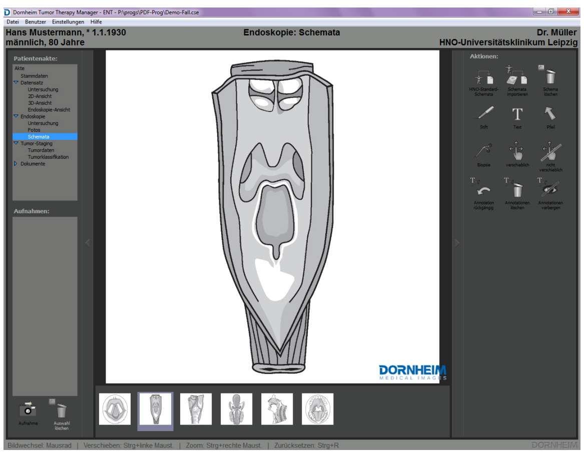

Figure 8: Schematic drawings of the neck anatomy are provided in electronic form in order to annotate them with findings from endoscopy.

Thus, it is desirable to adapt visual computing solutions to the peculiarities of such data. Multimodal visualization, including information derived from different image data is at least in some hospitals a useful extension. In particular, if radiation treatment or chemotherapy are part of the overall treatment plan, treatment response has to be carefully evaluated which gives raise to comparative visualization solutions highlighting how the shape and size of tumors have changed over time.

The development process and the derived needs are likely a good basis for a variety of surgical and interventional procedures. In particular, an in-depth task analysis with a focus on the clinical workflow and with user stories as a major means to communicate the process and its variants are relevant. Scenarios, in contrast to hierarchical task descriptions, state transition or workflow diagrams, are relatively vague and must be interpreted. However, due to their informal character, they are easily understood by all stakeholders and turned out to be a basis for fruitful discussions. In [2], we discussed in-depth how a surgical training system has been designed by means of a scenario-based approach.

However, we do not overgeneralize our experiences. Each disease, its diagnosis and treatment has certain peculiarities which need to be identified, interpreted and appropriately considered. Thus, interventions at the beating heart or in the brain require an understanding of many specific problems. Also, many interventions relate to deep-seated pathologies, where intraoperative imaging and intraoperative visualization based on preoperatively acquired data are essential.

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