The Tumor Therapy Manager and its Clinical Impact

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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 and illustrative renderings, usually fail to meet clinical demands, since the visualizations are not dedicated to specific diagnostic or 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 parameterization of visual effects is too cumbersome and 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.

1. Introduction

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. The planning process 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.

Ear-, Nose-, Throat (ENT) surgery is an example for a demanding medical field in which accuracy is often crucial. Due to the compact anatomy and complex functionality of the affected region, adherence of oncologically sufficient safety distances is always tightly coupled with the potential risk of functional losses, leading to more specific questions, e.g. *Can the larynx fully or at least partially be maintained so that the ability to speak is conserved?* Tomography data in this respect merely allow for identifying abnormalities, while slice-spanning measures like volumes and 3D distances require manual estimation and access planning turns out even more tedious. Facing this issue, 3D visualizations of the neck anatomy (Fig. 1) and inclusion of further modalities like endoscopic examinations (Fig. 3) and palpatory findings provide means to complete the surgeon's mental model.

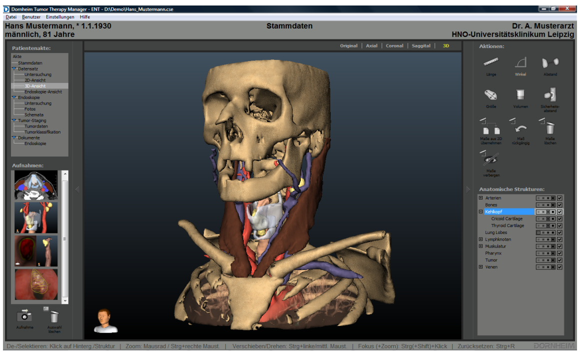

Figure 1: *Patient-individual neck anatomy as derived from CT data, shown in the TTM. Click left to activate embedded PDF3d model, right click for context menu. (Requires Adobe Acrobat Reader 7.0 or newer. Best viewed in fullscreen multimedia mode. Structure visibilities changeable. Predefined views result from dynamic snapshots created by TTM user.)*

2. 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 [D*10] and blood vessels [D*08] and advanced visualization of these structures, e.g. by cut-away views for emphasizing lymph nodes [K*05] and careful combinations of slicebased and 3D visualizations [T*06].

Two research prototypes, NeckSegmenter for segmentation and the NeckSurgeryPlanner for interactive exploration and surgery planning were developed and used in clinical practice since 2006. The clinical partners started to present these systems first internally, e.g. at the tumorboard, and later at their workshops and conferences [F*09, B*10] 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 (Dornheim TumorTherapyManager) ready for market and clinical practice.

3. In-Depth Task Analysis

As a major prerequisite for re-developing a research prototype into 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. This analysis was focussed on an understanding of:

1. individual surgical planning and preoperative decisions,
2. integration of information from multiple examinations,
3. collaborative treatment planning and tumor boards,
4. patient consultation, and
5. documentation.

To represent the results, informal scenario descriptions [Car00] 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.

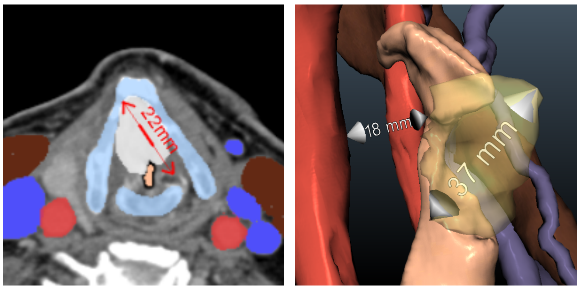

Figure 2: *Left: CT slice with overlayed structures and manual slice-spanning measurement of tumor extent. The intersection of the measure with the current slice is painted bold. Right: 3D visualizations of automatically computed extent of a tumor and its shortest distance to nearby arteria.*

3D Understanding The review and quantification of spatial relationships turned out to be crucial for preoperative risk assessment and access planning. This calls for detailled 3D understanding of the anatomical setting which cannot be fully provided by slice-based viewing of tomography data.

Infiltrations It turned out that infiltrations of anatomic structures by a tumor are investigated in detail w. r. t. their likelihood and extent. Thus, dedicated visualizations are desired containing just the risk structure, the tumor and the possible infiltration area (see Fig. 2 and the two user-captured views for thyroid cartilage the interactive scene in Fig. 1).

Volumetry Besides its extent and distance to or infiltration of nearby risk structures, the volume taken up by malignant tissue (Fig. 3) crucially determines possible therapy options.

Panendoscopic Findings Besides CT or MRI, endoscopic interventions are the most important source of information relevant for ENT surgical decisions. The surgeon investigates possible tumors using optical view and touch sense. Then, special sheets of paper with pre-printed schematic drawings of the neck anatomy are used to annotate the findings by hand (cf. complementary material). 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. Thus, any support which shortens the documentation is highly welcome.

4. The Tumor Therapy Manager

The whole development of the TumorTherapyManager (TTM) was guided by an understanding of the clinical workflow and resulted in a modular design of corresponding

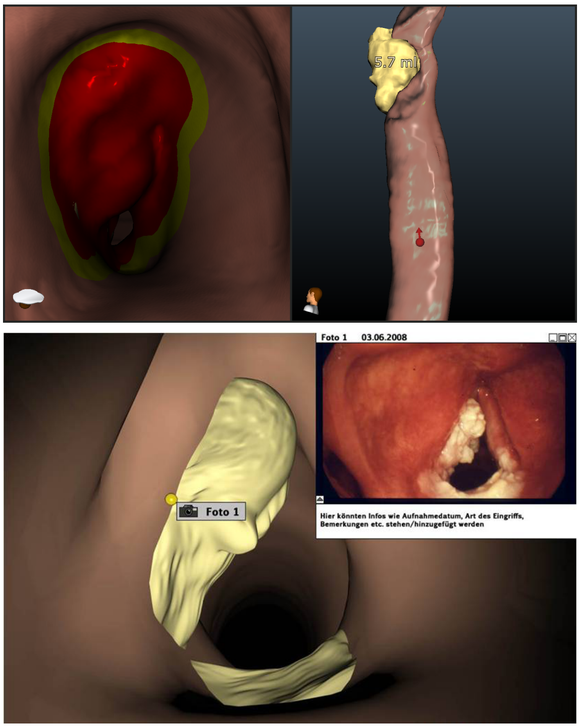

Figure 3: Top: *Virtual endoscopy and 3D context in side-by-side view.* Left: *Safety distance colorization of inner pharynx surface reveals outside contact areas.* Right: *Red glyph indicates view position and direction. A glass-like effect provides better visual perception than simple transparency.* Bottom: *For a tumor grown through the pharynx wall, a photo of the real intervention is attached to the corresponding position.*

components. Grouped around a central patient record, the basic workflow is made up by set of examinations, potential tumor staging, and the generation of documents.

Tomography Each examination covers basic examination information, acquired imaging data, resulting findings and therapy options. For modalities CT and MRT, the integrated DICOM-Viewer offers direct slice-based exploration of tomography data. If segmentations are available, their voxel masks can be selectively overlayed to the dataset. Apart from that, the TTM provides a 3D visualization of the corresponding surfaces. A new unified measurement approach [R*10] was implemented, capable of covering a variety of different distance based 3D measures (shortest distance, largest diameter, infiltration boundary, safety margins, etc.) for most different kinds of input (manual points, structures, groups, computed geometries like center points, skeletons, etc.). For optimal usability, the current view can freely be switched (axial, sagittal, coronal, 3D) during the running measurement. For specific structures (e. g., the respiratory tract) an additional virtual endoscopy is provided that allows examination of the interior. Although visualizations generated from CT or MRT cannot reflect the exact surface texture, an added value is given by revealing outside contact areas or combining virtual view with real photos (Fig. 3).

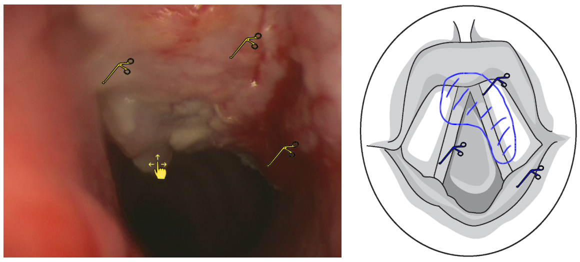

Figure 4: *The panendoscopy module offers easy annotation functionality.* Left: *An endoscopy photo enriched with exact biopsy positions and a hint concerning tissue movability.* Right: *A schematic pictogram annotated with the affected area and biopsy positions.*

Panendoscopy Real endoscopy itself is granted its own modality. Its imaging data consists of photos acquired during endoscopic examination and schematic drawings. For both types of pictures a user-friendly annotation system is provided – with freehand drawings, textual labels, and simple icons depicting important areas, (im)movable tissue or biopsy positions. Using the latter feature during endoscopy allows for unambiguous identification of biopsies by capturing id and position (usually a potential source of error). Besides visual evidence, these annotation features offer an easy way for incorporating also non-visual perceptions such as palpatory findings (Fig. 4).

Tumor Staging The tumor staging module provides form-based support for collecting tumor data and conducting a classification. For maximum support of the user, the application is capable of suggesting values whenever the information can be derived from the segmented geometries (e. g. sideness, laterality, quantity, or extent). A complete TNM classifier for ENT has been implemented to ensure that all relevant data has been gathered and that the resulting TNM classification is objectively correct (based on the expert's subjective assessment).

Documentation For any modality, snapshots of the current view (Fig. 1, left) can be made for the purpose of documentation. Besides plain screenshots, the 3D views also offer the possibility for capturing individual states of the scene and collecting them in an interactive 3D model (Fig. 1), thereby providing enhanced means for documentation and exchange of opinions (e. g. tumor board). The TTM's documentation module finally allows for incorporating the available information into documents of pre-defined format. Since LaTeX is used as generator, the layout is freely user-definable and can in particular be branded to the individual institution. At present, the panendoscopy document of the ENT department in Leipzig has been integrated (see complementary material). While collecting all previously provided data, a template-based textual finding is generated to save user time. All information can be altered and the snapshots can be inherited and reordered prior to invoking report generation.

5. Clinical Use

The TTM was developed and refined with the help of our clinical partners. Their expertise relies on a falling number in ENT tumor surgeries – for 2009, an annual quantity of 280 tumor initial diagnoses was reported. The TTM has been used for planning more than 100 neck surgery interventions so far. In most cases, a selected set of functions was used to visualize and quantify the tumors in their spatial surrounding. In some 40 cases, the full set of functions (including virtual endoscopy and documentation) were used.

The computer-assisted planning process was mostly performed in addition to the conventional one based on CT and paper. This was primarily done to serve comparison of the different workflows, and the TTM is at times being used exclusively now. 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). Although only in rare cases the overall surgical strategy was finally changed w. r. t. radicality or access, the surgeon feels much safer with the computer-assisted planning and generally better prepared for surgery.

The TTM is considered particularly useful for planning treatment of surgical interventions at the larynx, because all relevant target structures (cricoid and thyroid cartilage) can be segmented and discriminated well in CT data. With respect to oropharynx, not all relevant structures can be separated and thus the 3D visualization is less helpful at present. This, however, may change if segmentation is instead (or additionally) based on other modalities like MRT or PET/CT.

The surgeons employing the system report an observable added-value w. r. t. multiple aspects. The use of a common DICOM viewer is mentioned to be a big advantage over needing to deal with all the different ones coming along with DICOM CDs. Measurements are reported highly vitally, but are used for 3D much more than for 2D slice view. Annotation functionalities, in turn, are in general considered very helpful. The biggest value is thereby added by the fast and easily annotatable endoscopy photos and schematic pictograms. Altogether, the surgeons appreciate the distinct but user-friendly documentation features allows for the first time to communicate precisely the results of examinations like the panendoscopy, in particular the estimated depth-infiltration of vascular structures and other tissue (recall Fig. 3).

It turned out that, discounting the effort for segmentation, the computer-assisted planning process is slightly slower than the conventional one. This is in part due to the present need for manually entering patient information, importing CT data and endoscopy photos, etc. With a planned system-integration for PACS and HIS, large time savings can be expected. Yet, especially for difficult cases, the use of the TTM is already now being preferred, for it leads to findings of considerably higher expressiveness (see complementary material).

6. Conclusion

Treatment decisions in case of severe diseases 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.

The described 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.

Yet, we do not overgeneralize our experiences. Each disease, diagnosis and treatment has certain peculiarities that need to be identified, interpreted and considered.

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