The Tumor Therapy Manager – Design, Refinement and Clinical Use of a Software Product for ENT Surgery Planning and Documentation

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Abstract. The treatment of patients with head and neck cancers is a demanding medical field, due to the compact anatomy and complex functionality of the affected region. The planning process comprises issues regarding risk and applicability of intervention, extent of surgical removal, and the choice of appropriate access to the pathology. Required clinical information are obtained from different examinations, ranging from external visual and palpatory inspection, over preoperative panendoscopy and biopsy histology to radiological imaging.
The surgeon needs to process all available information in mind and virtually compile a mental patient model of the target anatomy. 3D visualizations of tomographic data may improve perception of spatial relationships. However, discussions with clinical practicians reveal that parameterization of advanced visual effects tend to be cumbersome and resulting visualizations are often too complex and not dedicated to specific diagnostic or treatment planning questions. Moreover, they will add valuable alternative views, but cannot replace all the other diagnostic sources.
We describe long-term experiences on developing and refining a software for ENT surgery planning and documentation. Regarding 3D visualizations, it turns out to be superior to generate sequences of rather simple 3D views directly supporting specific treatment questions, instead of presenting many anatomic structures simultaneously. Developing software for clinical practice thereby benefits from a thorough understanding of the target scenarios and the "visual questions" they raise. The second focus is on the seamless integration of the different diagnostic modalities, findings, and therapy decisions into a common electronic document. We report on the actual clinical use of the system and discuss how it fits into the surgical planning workflow.

Keywords: ENT, HNSCC, tomography, panendoscopy, segmentation, CAD, surgery planning, documentation

1 Introduction

The treatment of patients with head and neck cancers is more and more challenging in the regard of raising therapeutic alternatives and a multidisciplinary approach. Initial diagnostics is thereby considerably gaining in importance, not least due the growing multitude of chemo-therapeutic options – in addition to or as replacement for surgical interventions – that may involve potentially significant cost increases (medicament costs for chemotherapy of up to 40.000 EUR per patient). However, even continuously improving precision and quality of pretherapeutic imaging does not generally suffice to sound all therapeutic means exhaustively.

This in particular applies for interventional measures in ENT surgery. Complexity in anatomy of the head and neck here still results in difficulties in the preoperative planning even for well experienced surgeons. Tomography data can help identifying abnormalities, but do not always entirely reveal the overall picture of spatial relations in three-dimensional space, and not all kinds of malignant tissue may be directly visible based on CT or MR imaging. Additional findings are obtained via classical visual and palpatory inspection, in particular panendoscopy. At present, the surgeon is obligated to process all available information in mind and virtually compile a mental patient model of the target anatomy, including blood vessels, nerve supply, muscles and tendons, and more. The planning process comprises decisions on issues, such as applicability of an intervention, extent of surgical removal, selection of an appropriate access to the pathology, and exploration of adjacent anatomic structures to evaluate the interventional risk. Due to the compact anatomy and complex functionality of the affected region, adherence of oncologically sufficient safety distances thereby comes for the price of the potential risk of functional losses.

Facing this issue, 3D visualizations of the neck anatomy (Fig. 1) can provide a real added value, ranging from fast overview to in-depth visual-spatial exploration. Moreover, if they were obtained by segmentation of the relevant target structures, the corresponding 3D representations carry geometric information that can be used to generate visualizations directly supporting specific diagnostic or treatment planning questions, such as the volume or diameter of a tumor, its distance to a nearby risk structure, the existence of potential infiltrations, etc. The geometry may also be used for automatic semantic reasoning, e. g. in the context of tumor staging. Re-using available information is in general a beneficial objective. In fact, the combination of original tomography data, the derived 3D visualizations and the inclusion of further modalities and non-radiological information like endoscopic examinations, palpatory findings and histological results provide the best means to complete the surgeon's mental model and to support him in diagnostics, therapy planning, and documentation.

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

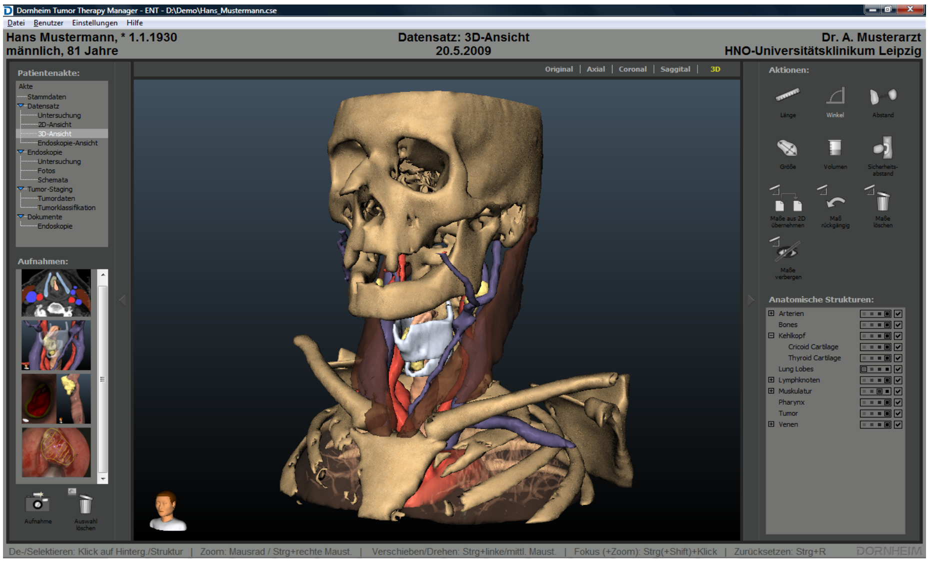

Fig. 1. Patient-individual neck anatomy as derived from CT data, shown in the TTM. Click left to activate the embedded PDF3d model, then right click for context menu. (Requires Adobe Acrobat Reader 7.0 or newer. Best viewed in fullscreen multimedia mode. Structure visibilities changeable. Predefined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

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 [1] and blood vessels [2] and advanced visualization of these structures, e.g. by cut-away views for emphasizing lymph nodes [3] and careful combinations of slicebased and 3D visualizations [4].

Two research prototypes, the NeckSegmenter for segmentation and the NeckSurgeryPlanner [5] 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 [6,7] 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

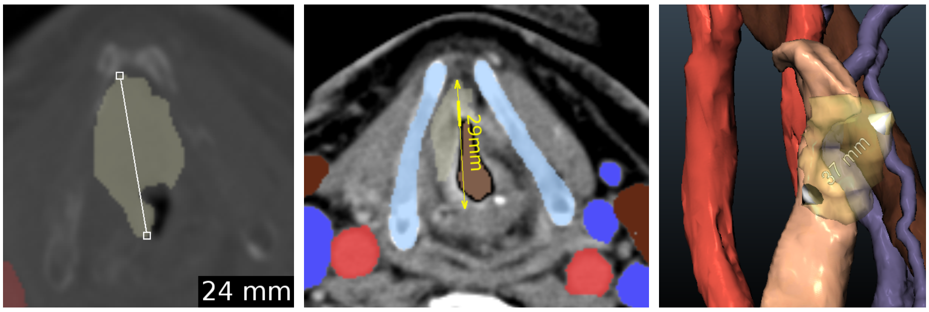

Fig. 2. Measurement of tumor diameter in a real clinical case. *Left*: The common practice of measuring by hand in selected axial CT slices suggested a maximum extent of 24mm. *Middle*: Support for slice-spanning manual measurements (intersection with the current slice is painted bold) provides means for assessing also the third dimension. However, finding the actual extreme points can be tedious. *Right*: If segmentations are at hand, the diameter can be derived fully-automatically. The tumor extent turned out to be more than 50% larger. The resulting measure can be visualized in 2d as a slice-spanning distance. A 3D scene, however, provides better perception of overall spatial relationships.

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 [8] 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.

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 (Figs. 2 and 3) which cannot be fully provided by slice-based viewing of tomography data (Fig. 2, left).

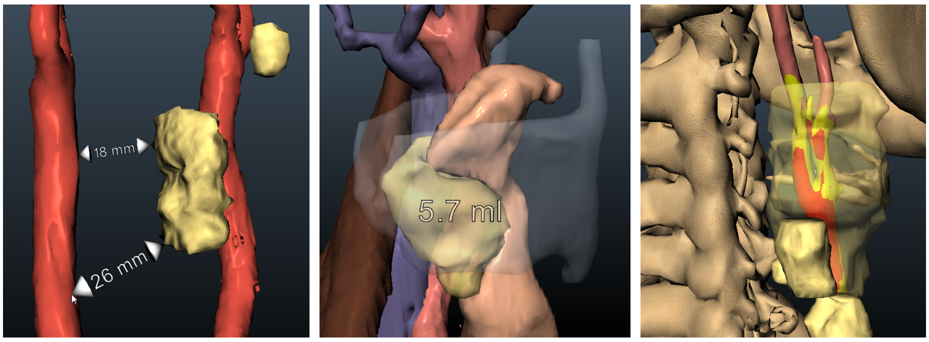

Fig. 3. 3D visualizations supporting specific treatment questions. *Left*: According to the given segmentations, the effective minimum distance between tumor and arteria carotis is 18mm. In case this measure is not expressive enough, the clinician can also fix the tumor and interactively discover the blood vessel's surface, retrieving the perpendicular to the malignant tissue in real-time. *Middle*: Volumetry for a tumor occupying the space between cricoid and thyroid cartilage and pharynx. *Right*: Color-coding of safety distance violation allows to assess contact and infiltration areas that are usually occluded. The figure shows arteria carotis color-coded w. r. t. the partially enclosing tumor and two violation levels (*yellow*=3mm or closer, *strong red*=1mm or closer).

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. 3 and the two user-captured views for thyroid cartilage within 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, middle) 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 (Fig. 7). 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 (Figs. 6 and 7).

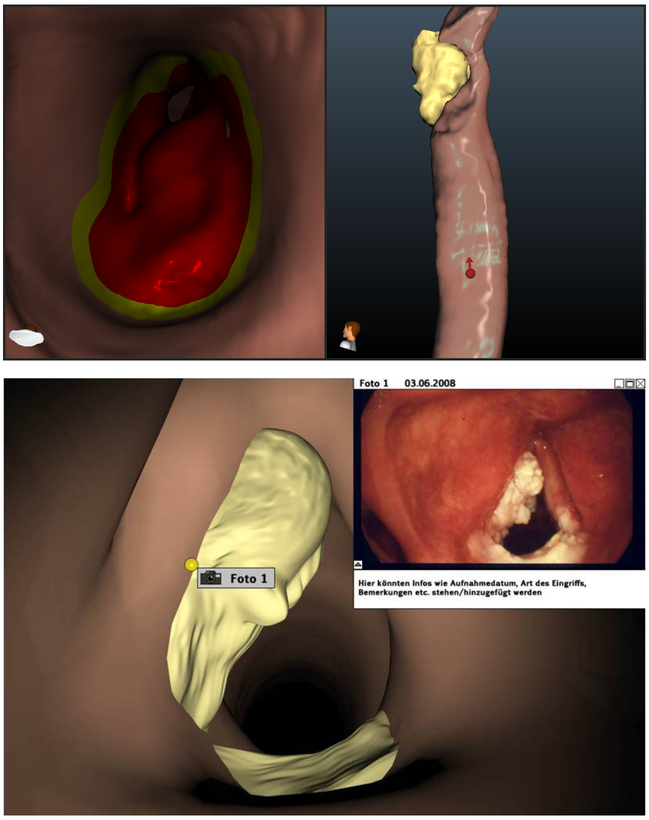

Fig. 4. *Top:* Virtual endoscopy and 3D context in side-by-side view. *Left:* Safety distance colorization of inner pharynx surface reveals outside contact areas. *Right:* Red glyph indicates view position and direction. A glass-like effect provides better visual perception than simple transparency. *Bottom:* For a tumor grown through the pharynx wall, a photo of the real intervention is attached to the corresponding position.

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 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 visual-

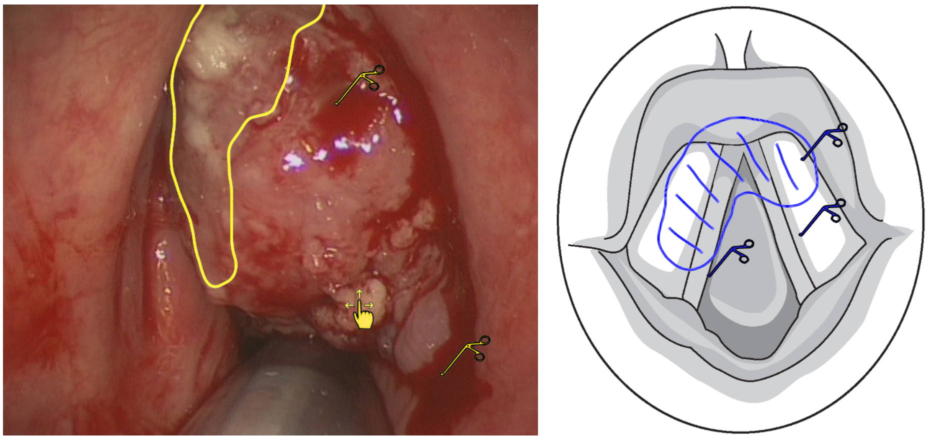

Fig. 5. The panendoscopy module offers easy annotation functionality. *Left:* An endoscopy photo is enriched with a line indicating the alleged tumor boundary, with markers depicting biopsy positions and with a hint concerning tissue movability. *Right:* A schematic pictogram is annotated with the affected area and biopsy positions.

ization of the corresponding surfaces. A new unified measurement approach [9] 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 closer examination of the interior. Although visualizations generated from tomography data like 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. 4).

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. 5).

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

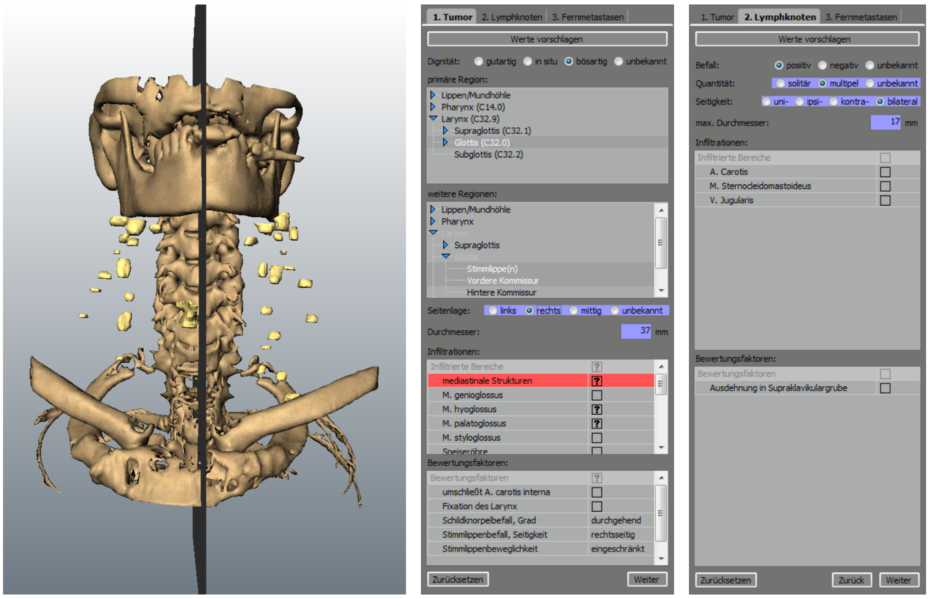

Fig. 6. Deriving information from the segmented geometries. *Left:* Based on a computed estimation of the midsagittal plane, sideness and laterality can be determined fully-automatically. *Middle & Right*: Suggested values (*blue*) for e. g. extent, quantity, sideness, and laterality ease up the process of tumor staging. *Middle:* The integrated TNM-classifier computes an objectively correct classification for the entered data and alerts in case of missing information.

can be derived from the segmented geometries (Fig. 6). That is, for the tumor and all malignant-marked lymph nodes, extent and quantity can be computed easily. Based on a computed estimate of the midsagittal plane (see [10]), also sideness and laterality can be determined fully-automatically.

Moreover, a complete TNM classifier for ENT tumors has been implemented to ensure that all relevant data has been gathered and that (based on the expert's subjective assessment) the resulting TNM classification is correct according to the official rules of AJCC and UICC [11,12]

Documentation For any modality, snapshots of the current view (Fig. 1, left bar) 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 (Fig. 7). Since LaTeX is used as generator, the layout is freely user-definable and can in particular be branded to the individual institution. At present, a template for the panendoscopy document sheet of the ENT department in Leipzig has been integrated.

Fig. 7. *Left:* Handwritten report. Four of six schematic drawings stay completely unused. Moreover, the handwriting is barely readable. *Right:* Electronic report. Only the meaningful schematic drawings are included. Photos, relevant CT slices and dedicated scene views are directly integrated into the document. Though not printable, also an interactive 3D model can be embedded. Endoscopy photos and schemes are enriched with helpful annotations (like important regions, biopsy positions, tissue movability and further haptic findings). Finally, the electronic text is much better readable.

While collecting all previously provided data, including the tumor staging performed, a template-based textual finding is generated to save user time. All information can be altered and captured screenshots 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. Although a clinical study aiming at an in-depth workflow-analysis is still running, some interim results and trends can be provided already.

The TTM has been used by 8 surgeons, mainly at the ENT department in Leipzig, 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).

Only in rare cases (less than 5%) the overall surgical strategy was finally changed w. r. t. radicality or access. Yet, a significant rate of change for the clinical decisions when using vs. not using this software-tool was actually not to be expected, for this would have meant that until now the clinicians were subject to considerably wrong decisions on a more or less regular base. Nevertheless, 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. 4). The involved surgeons report that with these functions they perform endoscopy more consciously and profoundly, since more findings can be reported.

It turned out that, discounting the effort for segmentation, the computer-assisted planning process is about 2min 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, additional time savings can be expected. Yet, since the expenditure of time stays within inter-surgery setup-times, the computer-assisted planning process fits into the clinical workflow. It has to be noted that the segmentation process, performed in advance, is quite time consuming at present (about 30min). Nevertheless, especially for difficult cases, the use of the TTM is already being preferred to the conventional planning and documentation, for it leads to findings of much higher expressiveness.

6 Conclusion

Treatment planning 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. The required information can be derived from most different medical data modalities. Since all of these modalities have their individual advantages and disadvantages, a combination and exploitation of all available information is desired. The slice-based investigation of tomography data provides a raw insight into the leison and is familiar to virtually any clinician. 3D representations, in turn, approve better descriptions of small and complex structures (relation of cervical lymph nodes to vessels and skull base) and structure-based semantic interpretation of the image data (extent of malignant tissue, minimal distance to risk structures in neck surgery). Finally, the integration of additional non-radiological information (visual and palpatory findings and histological results) completes the surgeons mental model.

Providing means for collecting, combining and re-using information from different modalities, the TTM thus offers a real added value for ENT surgical planning and documentation. However, the reported gain in perceived safety is in fact highly subjective to the individual surgeons. A desirable profound quantification of the achieved or achievable improvements, in turn, is limited by the inherent problem that examinations like the panendoscopy are actually not repeatable in the real setting. Up to now, no details are known on precision or deviation of reporting tumor finding and therapy decision. To overcome this issue, a dedicated panendoscopy phantom [13] is currently in development that will offer a way for performing panendoscopy examinations under identical predefined conditions and measuring the deviation of examination results in the context of a known ground truth.

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. Thus, it is desirable to adapt visual computing solutions to the peculiarities of such data. Advanced 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.

Nevertheless, 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 strong focus on the clinical workflow and with user stories as a major means to communicate the process and its variants turned can be considered instrumental and has proven successful also in the development of a surgical training system [14]. Yet, we do not overgeneralize our experiences. Each disease, diagnosis and treatment has in fact its very own certain peculiarities that need to be identified, interpreted and considered.

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