Computer-Assisted Interstitial Brachytherapy

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Abstract:
We present the current state-of-the art of computer-assisted interstitial (fractionated) brachytherapy as a "picture-book" without wanting to give an in-depth presentation of either brachytherapy itself or of otolaryngologic aspects of oncologic treatment. However, our results show that 3D-computer-assisted navigation techniques can successfully be applied in interstitial brachytherapy to exactly plan the hollow-needle's position(s) in order to reach a prospective planning of brachytherapy which exploits the full 3D-information of the modern imagery and incorporates state-of-the-art navigational techniques.

Patients:

All patients were informed about the nature of the treatment and gave their consent to participate in this clinical study. The tumors in the study included metastases of a hepatocellular carcinoma, adenoid cystic carcinoma (2 of the tonsil, 2 of the tongue, 2 of the floor of mouth, and 2 combinations thereof), 1 Schmincke carcinoma caudal of the sphenoid, in the pharyngeal space, and one secondary carcinoma of the tonsil. All together, 25 individual sessions were undertaken.

Materials and Methods:

The general approach is briefly outlined in the following. After an interdisciplinary discussion between the two departments (ENT and ROI) a palliative approach was chosen in all cases. The high-dose-rate brachytherapy is delivered fractionated to place, typically 30 Gy into the tumor, in ideally four sessions. Our approach is to insert the hollow needles every session anew in weekly intervals. Starting with a joint ENT-ROI definition of the optimal tumor target, the access trajectory, the number of needles needed to irradiate the tumor the procedure is defined. This plan implements an optimized patient positioning for treatment. Once the patient positioning is defined it is maintained throughout all sessions of therapy, unless intraoperative changes arise due to unforeseeable circumstances. The patient undergoes 3D-CT scanning (Siemens Somatom +, Germany) in the according position. We do, depending on the location of the tumor and depending on the general conditions of the patient, the scans either with or without general anesthesia. Typically, the patient is hospitalized for three days: at the very fist day of treatment the navigation is prepared: CT-Scanning, and creation of a 3D-reconstruction of the patient on the Allegro workstation (ISG Technologies, Canada), and setup of the Viewing Wand navigation system itself (ISG Technologies, Canada). The second day the intervention takes place under general anesthesia and the third day, to allow sufficient patient recovery and monitoring, the patient is released.

The navigation system:

This well-known 3D-navigation system comprises either a position sensitive mechanical articulated arm (Faro, USA) or the recent IR-LED equipped probes and the optical Polaris digitizer (NDI, USA).The ISG Viewing Wand allows to precisely determine the actual position within the patient's 3D-CT data set; the position is visualized as the origin of a set of crosshairs in the three regular CT views, multiplanar reformats and the 3D-reconstruction. More detailed information about the navigation system and related information can be found elsewhere.[1-5]

Initially, we used the arm itself to perform a real-time positional control of the brachytherapy needle. However, we found that the chance to bend the needles are substantial, especially when attached to the position-sensitive articulated arm. Based on laboratory investigations and cadaver studies we designed a targeting device which is in use now regularly. Moreover, the implementation of the targeting device allows to separate the planning process from surgery in time and space: we now do preplanning with the VBH-mouthpiece and the headholder in conjunction with the targeting device the day before the intervention. The alignment of the whole setup is kept throughout the whole duration of the fractionated brachytherapy unless intraoperative changes have to be made, like alterations of the alignment of the targeting device due to mechanical interferences with the patient etc. (*Nota bene*: this may occur since the planning is without the patient on the Viewing Wand and chest, shoulders or the cranial part of the thorax itself is not imaged!)

The patient fixation system:

The necessary immobilization is achieved by means of the VBH-headholder [6], a registration mouthpiece [7] and the navigation is set up according to a protocol developed in our clinic [8]. The patient immobilization device allows a reproducible and reliable patient fixation [9]; in combination with positional-control elements, the patient positioning can be verified and reliably adjusted for each session. These position control elements are, similar to the main components of the VBH-headholder, stabile fixable hydraulic arms with a sharp tip pointing to 4 well defined and - in the course of the up to 5 weeks lasting brachytherapy - constant patient anatomical features (warts, naevi, scars and so forth). Very recently we have started to treat "mobile" structures with 3D-computer-assisted navigation (i.e. structures related to the neck and the floor of the mouth, etc.). For this purpose we use, partly, whole-body fixation on base of a body-frame (ELEKTA, Sweden) with vacuum cushions and partly an exact fixation of the lower jaw, again and similar to the working principle of the VBH-headholder, based on an individual dental cast of the patient's lower dentition. This has been found to be reliable even in edentulous patients [10]. Pre-interventional planning of the optimum access path is either done by means of a targeting device [11] or intraoperatively [12] either with the mechanical arm to which a standard hollow needle attaches [13] or by insertion of either the arm's probe or the optical probe in the targeting device.

Results and Discussion:

In the cases where a well defined structure is present, the brachytherapy needle can be placed within millimetric accuracy in each of the sessions of the fractionated HDR-brachytherapy sessions. We have achieved an aiming accuracy of better than 2 mm in all spatial directions. In the cases where mobile structures, i.e. soft tissue is involved, accuracy goes down substantially. However, we still are able to substantially improve the repeatability and the availability of intraoperative positional information. As shown in the "picture book" the preplanned targets may be located with millimetric accuracy, constant throughout the sessions of fractionated therapy; in the cases where the tumor is not contained in the bony structures of the skull a needle placement within one centimeter of the preplanned position is possible, c. f. the last patient demonstrated.

Moreover, we have found that the time needed to conclude single session of interstitial brachytherapy may be reduced in special cases from eight hours to three hours.

Our approach represent possibly one of the first clinical approaches to realize interstitial computer-assisted brachytherapy of the whole ENT-head and neck region. Evidently, the best results can be obtained where the malign process is rigidly contained in bony structures, e.g. like a solitary retro-orbital metastasis of a hepatocellular carcinoma. It is necessary to note here that we do not want to give a rigorous treatment on brachytherapy; it is our intention to demonstrate the Innsbruck developments and the current clinical experience.

Conclusions:

As can be seen from the figures, we have already solved major problems and have achieved the key milestones to implement a prospective planning for brachytherapy, essentially by developing a versatile and reliable patient (re-) positioning and fixation device, intraoperative protocols and essential targeting devices for optimizing the placement of hollow needles into a tumor for interstitial brachytherapy.

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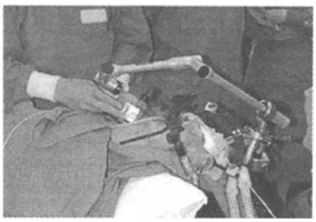
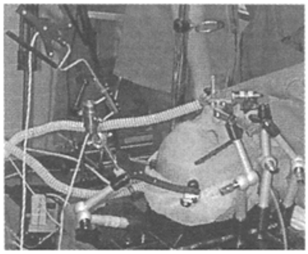
The picture book:

Intraoperative setup for the ISG "Freehand" System: Sauerwein Brachy therapy unit (left) IR camera (center) and navigation system (right) can be differentiated.

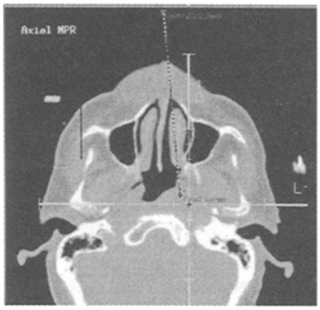
Same as before, but the position sensitive arm is used for intraoperative navigation, i.e. to adjust the targeting device through which the navigation system's probe is guided.



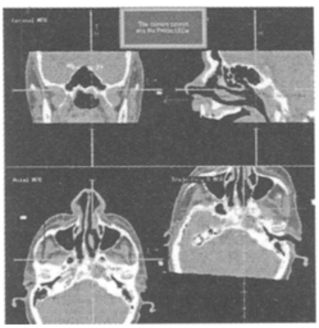
This view shows the setup for the optically probes of the ISG Viewing Wand The components of the holder, the ISG starburst and the ISG probe can be seen; the patient is now anesthetized and ready for needle insertion:



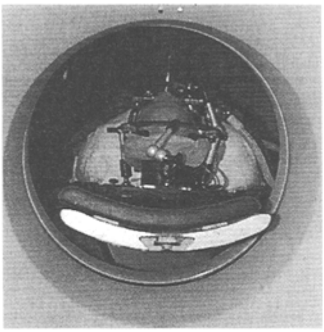
A typical preplanned needle position: left of the crosshair which shows the actual position in the axial data set the ideal target "target" is shown.



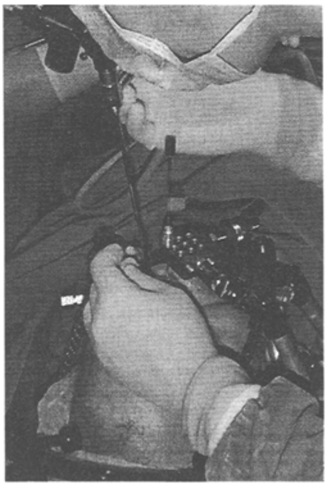
The distance from the targeting device to the tumor center, i.e. the stopping place of the radioactive seed, is shown in axial, coronal, sagittal and a trajectory view of the CT-data set.



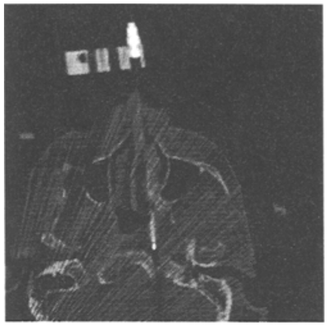
Planning of the brachytherapy session and verification of the actual needle position is done with the immobilized patient in the VBH-headholder; her a CT-based verification of the needle placement is shown.



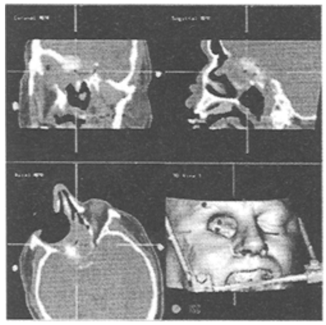
This shows the brachytherapy needle already inserted along the preplanned path with the help of the targeting device; at the moment an endoscopic inspection of the main nasal cavity is performed by the surgeon to check the macroscopic positioning of the needle in the Schmincke-tumor caudally to the sphenoid sinus



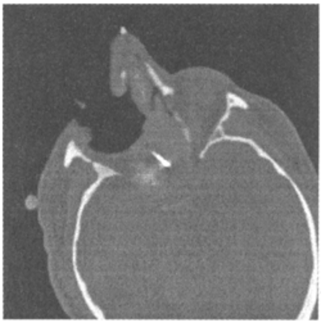
And here we have the final result of the achieved position, compre with the planned position!



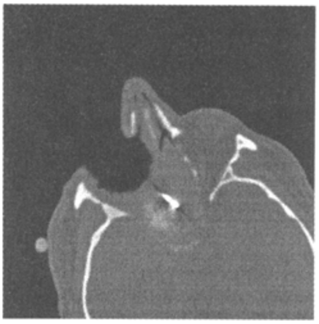
The next patient suffered from an adenoid cystic carcinoma of the paranasal sinuses; brachytherapy was performed after enucleation of the eye. In this patient the preplanned needle position is shown here; at the lower left components of the VBH-headholder are shown in a 3D-reconstruction.



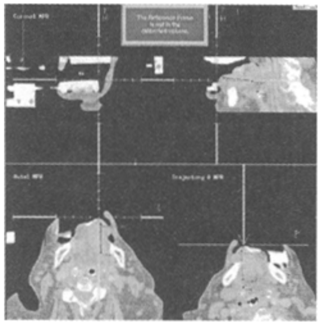
And here the results of two sessions: control CT-slices showing virtually the same positions of session 2



and of session 3:



Lastly, some ideas of interstitial brachytherapy in the floor of the mouth (here, we got coincidence between planned and achieved position in the cm-regime). However, positional information was sufficient. This figure is an intraoperative on-line screenshot during the planning session of accessing the posterior aspect of the floor of the mouth with all necessary hints: entry and target point, trajectory.



And this is how it looks like intraoperatively from a macro view with all hollow-needles in place. In this patient our new device for reproducible fixation of the lower jaw was used.