Radiotherapy with proton and ion beams is currently in a phase where the facility concepts of the first generation are slowly shifting towards new accelerator concepts. In addition the majority of the new facilities is equipped with scanning beam delivery systems. In the first generation facilities “standard” accelerators were used, meaning cyclotrons and synchrotrons, which were not specifically designed to be very small. Moreover, the vast majority of these systems are equipped with so-called passive beam delivery systems. In the meantime there exist several concepts for compact accelerators, like laser induced particle acceleration, dielectric-wall accelerators, very compact gantry mounted cyclotrons and compact synchrotrons. Only the latter two concepts have been realized, however, in clinical facilities, aiming to provide smaller and thus also cheaper single room facilities.

In contrast, the optimization of beam delivery concepts and especially fast scanning techniques for the treatment of moving tumors may have a stronger impact for the patients already on the short term. Besides fast energy switching the scanning speed is optimized in this case, to provide a drastically shortened treatment time and the potential for rescanning within a short time. Many of these improvements and developments are concentrating on proton therapy only, but also in the case of carbon ion facilities there is a continuous improvement of the classical synchrotron concepts towards fast switching of beam parameters to provide fast scanning and rescanning. In addition the first ion beam gantry came into clinical operation and novel, more compact, gantry concepts are under investigation. An overview of the latest developments, its status and perspectives is given in the presentation.

SP-0025
Intrafraction motion and proton beam scanning
A. Knopf

Currently newly built particle therapy centers are mostly equipped with scanning beams, since they provide highly conformal dose distributions when treating static targets. However, scanned beams face significant challenges when applied to moving targets. In addition to blurring effects, dose inhomogeneities can appear anywhere within a treatment field due to interplay between the delivery-time line and the time-line of motion. To mitigate motion effects, different approaches have been suggested. As the simplest solution, one can try to reduce the motion during treatment delivery through, for example, breath hold or gating techniques. In this talk, we would like to concentrate on motion mitigation techniques that are unique for a scanned beam delivery, namely rescanning and tracking.

The idea of rescanning is to statistically average out dose heterogeneities by repeatedly delivering the planned dose to the target with an accordingly reduced number of particles per scan. The risk of rescanning is the introduction of periodicity in the delivery time-line which can lead to interference phenomena with the periodicity of the patient motion. For a successful application of rescanning it is therefore essential to choose the right “flavor” of rescanning. Each specific way of scanning and each flavor of rescanning has its own characteristic delivery-time-line which is machine specific. In this presentation, we will show examples to emphasize that for a successful application of rescanning it is important to choose a way of scanning and a flavor of rescanning appropriate for your specific facility and adapted to the characteristics of each specific patient (motion characteristic, tumor size, tumor side).

Beam tracking for particle therapy refers to the lateral adaptation of pencil beam position, combined with appropriate energy changes to modify the position of the Bragg peak in order to compensate for target motion in all directions. Tracking relies on motion monitoring; ideally, real time 3D imaging should be employed or alternatively pre-treatment acquired 4DCT in combination with a motion surrogate. In current experiments the adaptation parameters are determined prior to treatment delivery based on 4DCT data, which leads to concerns about variations in patient anatomy and respiratory motion between the 4DCT scan and the time of treatment. For tracking, it is particularly important to minimize the time lag between the detection of a geometry change and the corresponding adaptation of the beam. By minimizing the time between pre-treatment imaging, potential online plan adaptation, and treatment delivery, these uncertainties can be reduced, but there is need to investigate the robustness of beam tracking, particularly over the time scales of fractionated delivery.

An optimal outcome for moving target geometries is probably obtained by combining different motion mitigation approaches. As there exist many different motion scenarios there is an optimal way to account for motion effects for each scenario. Perhaps the ultimate solution for the treatment of moving targets with scanned particle beams would be the combination of real time tracking and rescanning, so called re-tracking. However, to implement this clinically, online on-board 3D imaging has to be improved. A lot of developments, simulations and verifications have to be performed before such a technique could be used clinically.

Symposium: Minimising treatment volumes

SP-0026
Immobilization in radiotherapy: is it necessary in the age of image guided radiotherapy?
K. Lund

The use of radiotherapy as a method for tumor treatment is closely associated with toxicity in healthy tissues. Several methods have been developed to address this, using different techniques in an attempt to minimize the radiation dose to healthy tissues. Some techniques aim at reducing the clinical to planning target volume margins which account for the movement of the target as well as setup uncertainties. This presentation will focus on some of the essential interactions between internal and external immobilization techniques and image guided radiotherapy, beginning by describing three major factors which affect the outcome of radiotherapy: rotation, deformation and displacement. Some technique examples will be presented including immobilization of the prostate, the head and neck area and the rectum. The presentation will provide insights into the pros and cons of immobilization in an era of image guided radiotherapy.

SP-0027
Optimal in-room imaging: From 2D to MR
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In radiotherapy of cancer patients, accurate dose delivery is of the utmost importance. Not only to deliver the required dose to the tumor, but also to minimize the dose to the surrounding healthy tissue. Setup verification is therefore an essential part in the radiotherapy chain. Since the late 1950’s to present day, setup verification using in-room imaging, has evolved dramatically. As a result of this the role and responsibilities of the RTT’s in assessing these images and the impact on patients’ treatment has changed accordingly.

Initially, the most commonly used in-room imaging modality was megavoltage films. Only the bony structures could be visualized on these films. The RTT or the physician checked the position of the patient using these films, typically only during the first treatment session.

A big step forward occurred in the 1990’s with the introduction of portal imaging as a digital replacement of megavoltage films. The images were directly available and registration was automated. However, anatomical information was still limited and in 2D. The most used treatment techniques (AP/PA, 3vs or 4vs) resulted in large treatment fields and unnecessary irradiation of healthy tissue.

Not only bony structures, but also soft tissue can be visualized more accurately with the introduction of advanced in-room imaging techniques in the beginning of this century, like CT-on rails and Cone-Beam CT. Also advanced treatment techniques like IMRT and VMAT are becoming standard clinical practice. Together with improved in-room imaging target volumes can be reduced and healthy tissue can be spared. An important role for the RTT’s is to verify not only setup but also to ascertain if changes in anatomy during the RT course could result in under dosage of the tumor or over dosage of the organs at risk, resulting in an adaptation of the treatment plan. Moreover, the creation of a library of plans and daily selection of the optimal plan based on anatomical information is currently being evaluated.

In the last decade, the role of MR in radiotherapy has become increasingly important. The excellent soft tissue contrast of MR not only allows accurate tumor delineation, but also functional information of the tissue becomes available. As tumor delineation becomes more accurate, target volumes can be more accurately defined.

The development towards the integration of an MR and a treatment machine considerably improves the soft-tissue visualization and even functional information is available for image guidance. This improved image quality has the potential to enable daily re-planning in clinical practice. MR guidance entails an important change for the RTT’s, not only in image evaluation but also in decision making concerning the treatment. Changes in tumor position or tumor behavior are available during treatment and personalized intervention/adaption of the plan becomes possible.

Conclusion: In-room image guidance is continuously evolving from setup verification on low contrast 2D megavoltage films with standardized treatment fields, towards MR guidance and adaptation, minimizing target volumes and optimizing treatment for the individual patient.

SP-0028
Adaptive procedures in lung
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Survival rates for lung cancer patients treated with radiotherapy (RT) are poor partly due to the high rates of local recurrence. It has been shown that the local control rate may be improved for non-small cell lung cancer patients by increasing the RT dose. However, this requires high precision in the daily RT delivery, in order to minimize margins and avoid unacceptable normal tissue toxicity.

Large treatment margins have been used for lung tumours to account for respiratory motion and interfrational changes in the position of the primary tumour and the lymph nodes. The respiratory motion may be taken into account by use of time resolved 4D CT scans, whereby the respiratory motion of the individual patient is visualized. Implementation of gated treatment may lead to a larger margin reduction. The use of FDG-PET for target identification and delineation has increased the accuracy due to its high sensitivity and specificity.

The anatomy of the patient may change during the treatment course which leads to interfrational shifts in the position of the tumour and the lymph nodes. The most commonly used setup is based on the bony anatomy of the patient. However, a soft tissue match using the tumour reduces the treatment margins significantly. Minimal margins require daily online tumour match using for instance CBCT scans before each treatment fraction. In the majority of the patients, one or more of the lymph nodes are found to be malignant which complicates the soft tissue match as the nodes and the primary tumour may be subject to different interfrational shifts and thus, setup on both targets will not be perfect. It was found that setup on the primary tumour lead to underdosage of the lymph nodes in 10% of the patients[1]. In order to account for this, a threshold value for the interfrational shift may be used to select patients with systematic deviations above the threshold for re-scanning and re-planning, i.e. adaptive radiotherapy (ART).

ART is a radiation treatment process where the treatment plan can be modified using systematic feedback of measurements [2]. In case of anatomical changes this implies re-scanning and re-optimization of the treatment plan. Tumour shrinkage and irreversible fixation may lead to systematic interfrational shift of the tumour and the lymph nodes. Large anatomical changes are observed in 23 % of the patients[3]. These changes include appearance / disappearance of an atelectasis, pleural effusion or pneumonia/pneumonitis. These changes may lead to geometrical changes of the targets and/or to dosimetric changes due to changes in the density of the tissue (see Fig 1). In both cases underdosage of the tumour/lymph nodes or overdosage of the normal tissue may result. It has been shown that anatomical changes have a larger impact on the dose distribution than changes in the respiratory motion or interfrational shifts[4]. Therefore, most patients experiencing anatomical changes may benefit from ART[1,5,6].

In addition, tumour shrinkage during the RT course, enables dose escalation to the primary tumour with without increasing the normal tissue toxicity[7]. The implementation of ART requires education of the radiation therapists. In our clinic, a programme with e-learning, hands on training and an individual test was setup before clinical start. Furthermore, ART requires a well-defined workflow for re-scanning and re-planning of quite a lot of patients. And finally, daily online soft tissue matching followed by evaluation of the tumour and lymph nodes will prolong the treatment time compared to a bony anatomy match. In our clinic the treatment time was prolonged by 3 minutes.