Advances in Image-guided Radiotherapy – The Future is in Motion

a report by

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Introduction

External beam radiotherapy is the most common form of radiation treatment offered to cancer patients. Currently, different types of external beam therapy techniques are used. The goal of three-dimensional conformal radiotherapy (3-D CRT) is to deliver a full dose of irradiation to the target structure with as little radiation as possible to the surrounding normal tissue. Intensity modulation radiotherapy (IMRT) is a further refinement of conformal radiotherapy, which allows the dose within a target to be modified so as to spare specific tissue and organs. In order to take respiratory motion of the target into account, another approach is 4-D CRT, which can also be combined using intensity modulated fields.

Historical Overview

Different approaches towards image-guided radiotherapy (IGRT) have been followed over the years. In the 1990s, the first electronic portal imaging devices (EPID) for linear accelerators (linacs) were developed, initially with charge-coupled device (CCD) camera optics, later using liquid ion chamber technology and now mostly based on amorphous silicon flat panels. The next step has been the introduction of room or gantry-based kilovoltage (KV) radiograph and fluoroscopy devices, also allowing localisation by means of bony structures or fiducial markers.

Initially, obtaining 3-D information was achieved by placing a conventional computed tomography (CT) scanner in the treatment room in a known geometric relationship with the linear accelerator's isocentre. Now, CT functionality has been integrated in the linac in order to eliminate the need for a separate scanner. These cone beam CT options are based on either an additional kV system or by using megavolt radiation from the therapy beam source. Most recent publications indicate that on-board imaging devices with a separate kV system offer the largest flexibility with regard to different modes such as radiography, fluoroscopy and CT.

4-D Imaging

Most 3-D treatment planning systems utilise CT images based on a diagnostic CT scanner. These scanners limit how the patient can be positioned because of their relatively small opening; in order to overcome these issues, dedicated oncology scanners with a large bore have been developed. The new radiotherapy department at the Hirslanden Klinik Aarau was one of the first clinics in Europe to be equipped with a special radiotherapy scanner (see *Figure 1*). Such multi-slice systems with up to 20 detector rows now allow the acquisition of high-speed scans. These scanners additionally offer 4-D functionality, which means the scans are acquired with co-registered respiratory signals. This technique entails the creation of multiple CT slices at each relevant table position for at least the duration of one full respiratory cycle, while simultaneously recording signals from a respiratory motion monitoring system.

As a consequence, 4-D imaging is part of IGRT because, in order to function effectively, like with gating, 4-D imaging capability is required. The crucial element of the gating system is that, unlike some others, it is a non-invasive form of gating that works via room-mounted cameras and a detector device that is placed on the patient's torso. It records the patient's breathing pattern during the scan, resulting in a 4-D-CT data set. An analysis of the data with regard to target motion during the different phases of the breathing cycle by the radiotherapist and medical physicist determines the minimum movement and leads to the therapeutic window defined by a lower and upper threshold.

On-board Imaging

Aarau was only the second European hospital to install an on-board imaging system for IGRT, as shown in *Figure 2*. Last July, the new radiotherapy department at the Hirslanden Klinik Aarau was equipped with one of the most advanced and sophisticated radiotherapy systems in the world today. In addition to the on-board imager (OBI), which is used to fine-tune patient positioning at the

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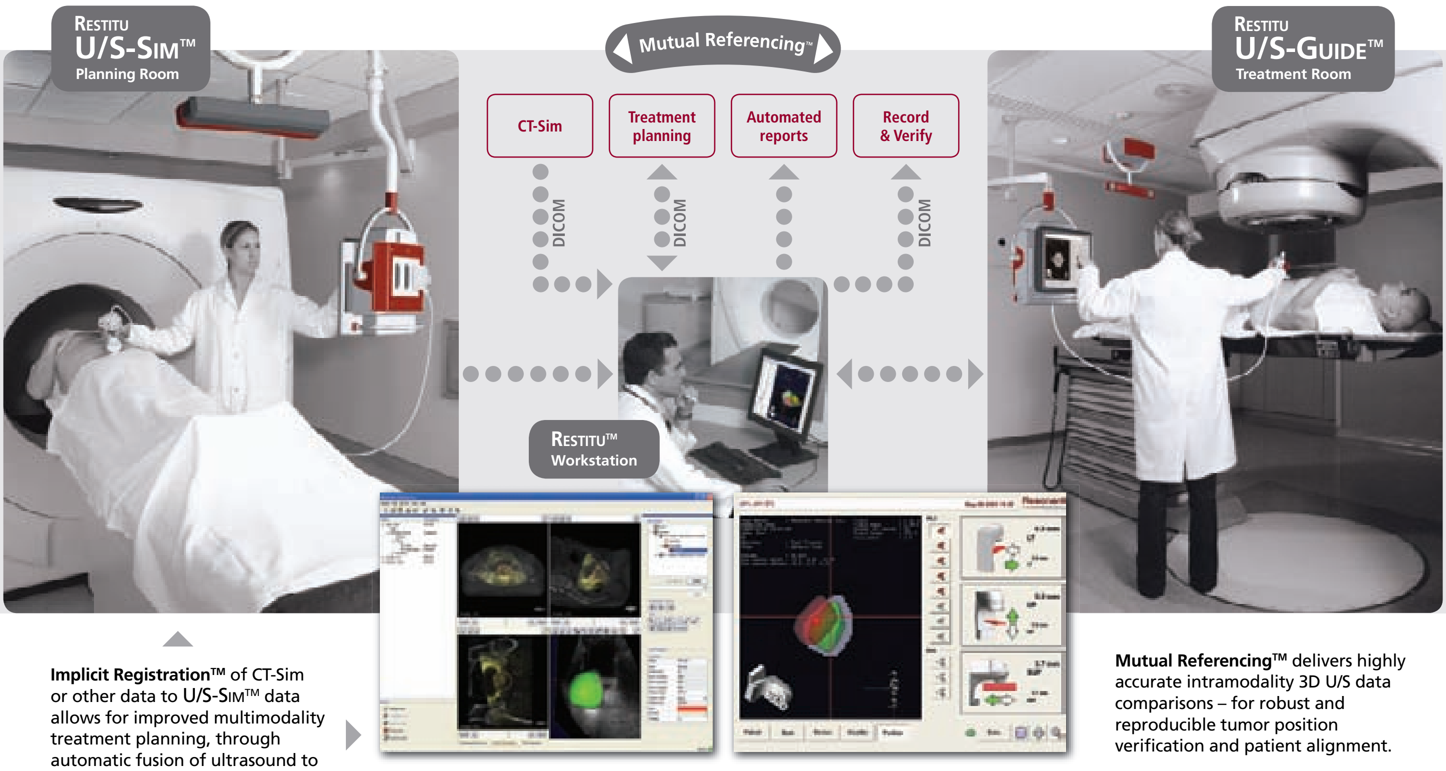

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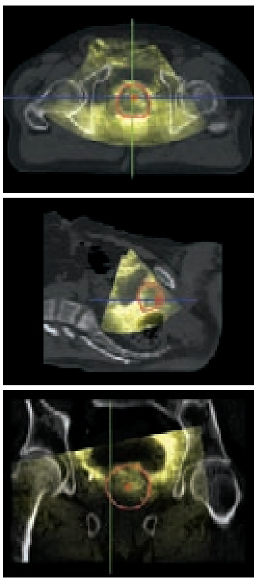

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Figure 1: Radiotherapy CT-scanner with Large Bore and 4-D Capability

time of treatment, the system incorporates the realtime position management (RPM) respiratory gating system, which tracks tumour motion and turns the treatment beam on and off as the tumour moves in and out of range. A gated treatment is illustrated in *Figure 3*, showing the patient with the detector device (two reflector spots) in the upper left corner and the breathing curve with inhale and exhale period information in the lower right corner. By 'gating' the treatment beam, doctors are able to deliver a more precise dose to the tumour and avoid more of the surrounding healthy tissues.

The OBI is a digital imaging device mounted on the treatment machine via robotically controlled arms that operate along three axes of motion. No other imaging device for radiotherapy has this range of motion. This allows the imager to be positioned optimally for the best possible view of the tumour and surrounding anatomy. The device produces high-resolution images of the tumour, and it can track tumour motion to provide doctors with a clear indication of exactly how a tumour will move during treatment due to normal breathing and other physiological processes.

Prior to the advent of IGRT and tools like the OBI and RPM gating, radiation oncologists had to contend with variations in patient positioning and with respiratory motion by treating a larger margin of healthy tissue around the tumour. IGRT is expected to enable doctors to minimise the volume of healthy tissue exposed to the treatment beam.

As well as these key IGRT solutions, the clinic's radio-oncology department also implemented an entirely paperless and filmless working environment, utilising a dedicated radio-oncology management system, offering verification and recording as well as image management functionality. It incorporates an additional electronic patient chart that is totally customisable and allows a seamless data transfer, and is linked to all the hospital and institute systems. As a result, all patient data including images can be retrieved at every workstation.

Aarau has treated about 300 patients to date using the OBI, primarily for breast and prostate cancer, in the thorax region used in conjunction with gating. Indeed, Aarau is the only clinic doing gating in Switzerland. It is treating breasts (left and right side), and is also treating every lung cancer with gating and using the fluoroscopic pre-treatment set-up verification on the OBI. For the very first time, this modality enables the physician to look into the patient and to analyse the target volume movement prior to treatment. The assumptions based on the 4-D-CT scan information can therefore be verified in realtime with regard to possible changes in breathing pattern, i.e. due to treatment-induced tumour regression.

At present, 45 patients are being treated per day, 15 of them with gating. Cone beam CT (CBCT) has been used for about 50 patients who have undergone a CBCT scan but at the moment more experience with the image quality is needed, with exploration of the possibilities of what it is capable of before it is incorporated into routine clinical use. Initial problems with its stability have been solved and it has already been used for treatment planning. Comparisons have been conducted between diagnostic CT scans and CBCT scans to the same patient and the relative dose distribution is approximately the same.

The fluoroscopic mode offers the first chance to really look into the patient and analyse whether the movement of the target for the gating threshold is really correct. It allows for decreasing the margin, which obviously benefits patients, and it reduces side effects. Every breast is being treated with a form of IMRT called e-compensation, which has enabled a reduction of the dose maximum from 125% to just 105%; using this, the skin reactions are dramatically decreased and the side effects are much better, bringing down the dose to the heart to zero in some cases. By using these imaging and treatment techniques, the patients' experience is far better.


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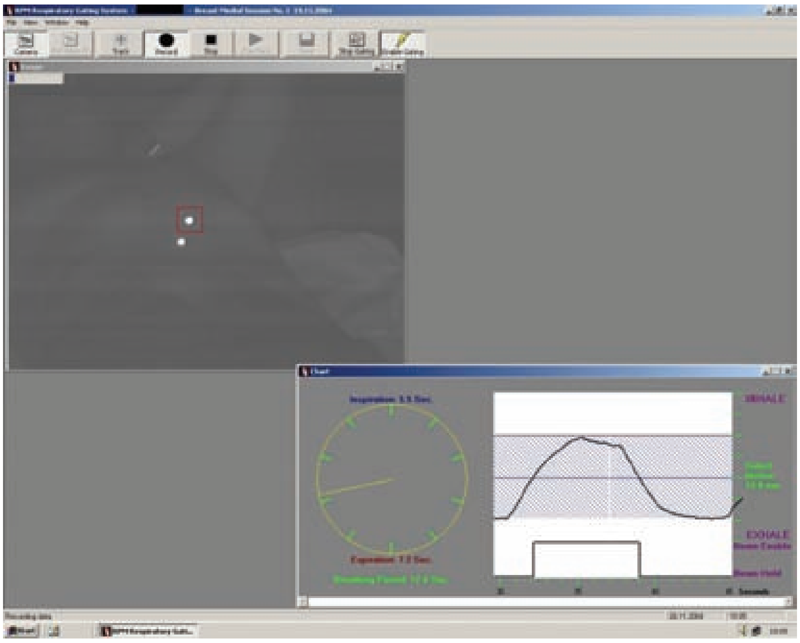
Figure 2: Linear Accelerator with On-board Imaging

Figure. 3: Radiation Treatment Using Respiratory Gating Technique



Future Perspectives

The next step for work with on-board imaging will involve online 3-D/3-D matching. This would enable a genuine 3-D repositioning of the patient as well as offering the best way to make use of the CBCT dataset – CBCT is the only way to gain genuine 3-D information about the anatomy.

Although the clinic is currently limited because the couch only allows four degrees of movement, it is exploring the possibility of gantry or collimator rotation, which could compensate for the problems of the two degrees of motion missing in the basic therapy couch. Another approach considered is the integration of a six-axis couch, allowing a real 3-D repositioning. This solution – in a dynamic repositioning mode – would offer the possibility of realtime compensation for respiration-induced target motion. The integration of such a system is now evaluated in order to overcome the problem of treatment time prolongation due to the duty cycle (beam hold time) being dependent on the individual target volume movement.

Another goal is to achieve online re-planning, for which it is crucial to have automatic segmentation and follow the tumour shrinkage and changes in the structure. With this, an automatic re-contouring of target structure is needed. It is currently possible to conduct re-planning based on the CBCT slices but is it not possible to do it within a process that is three minutes long. At the moment, the online matching is only manual. The data can be exported into Eclipse but that takes time. Offline planning takes 10 minutes, so it would double the treatment time and that is no good – if it takes 10 minutes, this type of re-planning cannot be introduced. At the moment, the CBCT solution is integrated in a way that takes five to eight minutes, which is too long for regular use in routine clinical treatments. Anything that lengthens treatment times unduly must be avoided.

Online re-planning would really mean having the patient on the couch, conducting a CT scan and analysing the scan to judge whether there is a tumour shrinkage. Is the field size still correct or should it be increased or decreased? With these new tools, all the assumptions made so far could become things of the past. If, for instance, lymphoma (which shrinks very quickly) is being treated how does one take that reduction into account for the following sessions? The CT scan takes about one minute and a huge amount of data is collected. As already mentioned, the reconstruction can be accelerated so it takes half the time it takes today, but still more is needed. It is better than nothing, even though the clinic is always one session behind (because it is taking the new situation into account for the following session rather than the current session), but it is still a major step forward from where it was.

Auto segmentation is also a vision for the future – this involves an initial automatic contouring of the target volume depending on whether there is a clear border between the target and other anatomical structure. If not, there is the question of tumour response – it would make sense to integrate this for re-sizing the fields. The clinic would welcome a tool that supports this type of treatment to the target volume by allowing it to be done manually the first time, but afterwards enabling one to analyse the electron density (Hounsfield units) of that target structure and look into the new CT scan to see whether the structure is smaller. This could then be used as the new contour structure for the target volume. ■