

ARTICLE

Defining the radiation target on a daily basis

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Abstract

The delineation of the target volume for irradiation is a critical step in the radiotherapy process. Delivery of radiotherapy occurs over a fractionated course of many treatments. Variations in the position of the target volume may occur on a daily basis during treatment and so the procedure for defining the target volume on a single initial 'snapshot' computed tomography scan has been re-evaluated. Newer technologies of image-guided radiotherapy allow the development of on-line daily definition of the target volume prior to radiotherapy delivery.

Keywords: *Radiotherapy; target volumes; image-guided radiotherapy.*

The need for target volume verification

Advances in the delivery of radiotherapy treatment, such as multileaf collimators and three-dimensional (3D) treatment planning systems, allow us to plan and deliver increasingly more conformal treatments. Evidence exists for lung, head and neck and prostate cancer that dose escalation leads to improved clinical outcomes. The ability to deliver high dose radiotherapy to an accurately defined and shaped target volume with minimum dose to surrounding tissues hence improves the therapeutic ratio and reduces normal tissue morbidity.

It is well recognised that there are 'set up' variations on a daily basis during a fractionated course of radiotherapy which may be delivered over up to 35–40 treatments^[1]. These result from daily uncertainties in the immobilisation of the patient and their position, patient preparation, staff experience, and machine parameter variations. These geometric errors are made up of both systematic and random errors and each radiotherapy department has a verification programme for each tumour site^[2]. This ensures that these geometric uncertainties are measured and then used to define the margin around the clinical target volume (CTV) to make up the planning target volume (PTV). The planning target volume is a geometrical concept which ensures that the CTV receives

a tumouricidal dose every day in its entirety, by adding a margin around it for 'set up' errors^[3].

Commonly, electronic portal imaging (EPID) is used on the treatment unit and compared with the digitally reconstructed radiograph (DRR) or simulator film used at TV localisation.

Organ motion during radiotherapy

With the publication of studies of organ motion^[4,5] there is now an increasing awareness that there is internal organ motion which is physiological and may affect the position of the target volume during treatment delivery. This may be predictable (respiration and cardiac pulsation) or unpredictable (bladder and rectal filling, swallowing, small bowel motion). Current EPID based verification of 3D conformal treatment only visualises bony anatomy and therefore cannot identify movement of internal organs. These individuals are therefore at risk of geographical miss of the target if it has moved significantly from the initial localisation computed tomography (CT) scan position. The clinical benefits of highly conformal treatments will clearly not be realised unless this internal target volume motion is quantified and compensated for where necessary. In order to meet this

need, a form of 3D verification has been developed called image-guided radiotherapy (IGRT). This encompasses technologies which quantify errors in target volume position during delivery of radiotherapy and either reduce or compensate for them. Methods of IGRT include: implanted fiducial markers^[6,7], ultrasound^[8], in-room diagnostic CT or kilovoltage X-rays, kilovoltage cone beam CT^[9], and megavoltage cone beam CT^[10].

Prostate motion can be indirectly quantified using implanted radio-opaque prostate markers such as gold seeds, which can be visualised using EPID. The use of ultrasound for localising the prostate on a daily basis prior to treatment is described by Lattanzi *et al.*^[8]. The disadvantages are that it requires a bladder fuller than that used for radiotherapy, it can be observer dependent and it has to be compared with the original CT dataset, i.e. a different imaging modality. In-room diagnostic CT involves a treatment couch on rails moved into the diagnostic CT scanner, but the image acquisition is not in the actual treatment position. In-room kilovoltage X-ray imagers are used to track fiducial markers in 3D using fluoroscopy^[11]. Kilovoltage cone beam CT uses a kV imaging device integrated into the gantry of a megavoltage linear accelerator.

CT imaging on a linac is limited by the speed at which the gantry can safely be rotated. An X-ray volumetric image (XVI) is reconstructed from a 'cone beam' of X-rays acquired during a single gantry rotation. This requires an amorphous-silicon flat panel detector and fast 3D reconstruction algorithms. Several systems are now in clinical use worldwide. Megavoltage cone beam CT or tomotherapy uses a megavoltage beam mounted on the ring gantry of a CT scanner. Megavoltage CT images are acquired with the patient in the treatment position.

Prostate motion

Many studies in the literature^[12–14] have contributed to data on prostate motion showing that differential prostate motion occurs with the seminal vesicles and base of prostate moving more than the apex.

Recently a publication by Crevoisier *et al.*^[15] showed in a retrospective analysis that rectal distension on the initial CT planning scan correlated with reduced cure rate for patients with prostate cancer. A series of 127 patients at the MD Anderson Hospital treated with 3D conformal radiotherapy to 78 Gy in 1993–1998 formed the study group. A retrospective analysis was made of their initial CT planning scans with measurement of the rectal volume. Rectal distension was measured using an average rectal cross sectional area (CSA) = rectal volume/length. Results showed that for patients whose rectum was distended with a CSA > 11.2 cm², the 5 year prostate specific antigen (PSA) control rate was only 63% compared with 92% for those with CSA < 11.2 cm² ($p < 0.001$). This shows that a distended rectum on the initial CT scan leads to a systematic error in localisation of the

prostate, which on a daily basis may drop posteriorly out of the target volume when the rectum is empty, resulting in a geographical miss.

The patient should be given dietary instructions to void the bowels prior to CT scan and treatment, or regular laxatives considered. The lack of reduction of this prostate motion with attempted use of rectal balloons has recently been reported by Van Lin^[16].

Prostate displacement correlates less strongly with bladder volume but instructions are given to patients to maintain a constant bladder volume prior to planning CT scan and daily treatment.

An alternative to tracking markers on the prostate, to ensure accurate target localisation on a daily basis, is the use of adaptive radiotherapy (ART). Martinez *et al.*^[17] discussed a series of 150 patients who were planned conventionally using a 1 cm margin around the CTV to create the PTV, in order to allow for geometric uncertainties including prostate motion. Daily CT scans were taken on the kV cone beam CT on the first 4 treatments days, as well as daily portal images. A new PTV was delineated using the actual systematic and motion errors measured on each individual patient using the initial CT and 4 subsequent scans. The mean volume reduction in target volume was 24% (range 5%–43%). ART allows the creation of a patient specific margin rather than using a generic 1 cm CTV–PTV margin. It reduces size of the target volume and ensures measurement of patient specific errors.

Organ motion studies have also been carried out in the lung, where respiration causes motion of lung tumours during radiotherapy, particularly in the peripheral and lower lobes. Methods of suspending respiration include active breathing control^[18], gated CT scanning and respiration correlated CT scans. These techniques allow reduction in the CTV–PTV margin which is otherwise required to ensure delivery of dose to the whole tumour if the patient is breathing normally.

Less data are available on bladder motion during radiotherapy delivery. However serial CT studies^[19] show that the bladder is subject to significant motion over the treatment course requiring margins of 1.5–2.5 cm for CTV to PTV, especially in the cranial direction. Adaptive radiotherapy and good patient instructions can reduce these margins considerably, as can the use of cone beam CT prior to radiotherapy delivery.

Summary

Standard portal imaging based verification systems on most treatment units use 2D bony anatomy as the verification end point. This cannot visualise or quantify or compensate for internal organ motion on a daily basis. The use of fiducial markers for lung and prostate cancer and kV and MV cone beam CT scanners integrated with linear accelerators provide high quality volumetric images which can now be used for 3D verification

of the actual daily target position. This will provide individualised 3D target verification on a daily basis ensuring that highly conformed radiotherapy is delivered accurately.

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