PhD thesis: "3D dose verification for advanced radiotherapy"

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This work on dose-guided radiotherapy (DGRT) resulted in a comprehensive thesis for verification procedures in 3D both for pre-treatment verification and *in vivo* dosimetry.

With the introduction of the amorphous silicon type EPIDs in 2005 the calibration of these EPIDs for portal dosimetry was investigated by the Maastricht group, and this type of EPID was calibrated for accurate dose measurements [*Nijsten, van Elmpt et al, Med. Phys. 34:3872-84 (2007)*]. In 2005 the topic of this PhD-project was broadened from 2D verification measurements to dose verification in three dimensions (3D). This project aims for quality assurance of radiotherapy treatments at two stages: 1) pre-treatment verification and 2) treatment verification / *in vivo* dosimetry.

The 3D pre-treatment verifications are performed prior to actual patient treatment but after all preparation work, e.g. planning CT-scan, treatment plan optimization, data transfer to linear accelerator. A 3D pre-treatment verification model was developed that reconstructs, independently of the treatment planning system (TPS), the dose that will be delivered to the patient. The method was based on the measured treatment fields at the linac prior to treatment with the EPID calibrated for dose measurements and an accurate dose calculation engine based on the Monte Carlo code XVMC [*van Elmpt et al, Med. Phys. 33:2426-34 (2006)*]. In a later study, [*van Elmpt et al, Med. Phys. 34:2816-26 (2007)*] this approach was extended with a verification of the dose calculated with the TPS (CMS, XiO) and detected differences in dose behind blocked regions of the treatment field due to an erroneous implementation of the jaws above the multi-leaf collimator. Patient results for head-and-neck and lung cancer treatments were published [*van Elmpt et al, Radioth. Oncol. 86:86-92 (2008)*]. The fact that dose is reconstructed in 3D eases the interpretation of possible differences in terms of dose to the tumour or dose in normal/critical structures. This allows the evaluation of the delivered dose distribution in terms of dose-volume histograms and isodose surfaces projected on the planning CT-scan. Therefore, 3D dose reconstruction is a significant step forward compared to 2D verification.

The second part of the PhD project was focused on the development and validation of verification procedures during treatment: **3D *in vivo* dosimetry**. A method has been developed that combines both dose delivery measurements of the treatment machine and accurate patient anatomy acquired with the latest solutions in image-guided radiotherapy (IGRT). First, the patient anatomy is acquired using an on-line megavoltage cone-beam (MVCB) CT scanning prior to treatment. We developed a method to correct the low-dose MVCB CT scan for cupping artefacts and calibrated the images for dose calculation purposes [*Petit, van Elmpt et al, Med. Phys. 35:849-65 (2008)*]. Second, the treatment beams behind the patient are measured during treatment and used to reconstruct the dose that is delivered to the current patient model in 3D for that particular fraction. The model corrects for patient scatter reaching the portal imager, the energy fluence is back-projected through the on-line MVCB CT scan and the dose distribution is calculated from an accurate Monte Carlo dose simulation. Applicability and high accuracy was demonstrated using a phantom and patient study; this work was published in 2009 [*van Elmpt et al, Int. J. Radiat. Oncol. Biol. Phys. 73:1580-7 (2009)*].

The concept of 3D dose verification allows for adaptive radiotherapy: changing from planned dose distributions calculated prior to treatment to effectively administered dose distributions delivered to the patient during the course of treatment.