Physica Medica 46 (2018) 81–88

Contents lists available at ScienceDirect

Physica Medica

journal homepage: www.elsevier.com/locate/ejmp

Original paper

Image guidance in clinical practice – Influence of positioning inaccuracy on the dose distribution for prostate cancer

Katharina Bell*, Yvonne Dzierma*, Melanie Morlo, Frank Nüsken, Norbert Licht, Christian Rübe

Department of Radiotherapy and Radiation Oncology, Saarland University Medical Centre, Kirrberger Str. Geb. 6.5, D-66421 Homburg/Saar, Germany

ARTICLE INFO

Keywords:
Prostate
IGRT
Positioning accuracy
NTCP modelling

ABSTRACT

Background: In order to consider potential positioning errors there are different recipes for safety-margins for CTV-to-PTV expansion. The aim of this study is to simulate the effect of positioning inaccuracy with clinically realistic patient treatment plans.

Methods: For a collective of 40 prostate patients, the isocenter was shifted back appropriately to the applied table shifts after positioning verification, simulating that no positioning correction had been performed and the treatment plans were recalculated. All the treatment fractions with the appropriate isocenter-shifts were added to yield a new plan considering two scenarios:

1) Extreme scenario: summation of only shifted plans.
2) Realistic scenario: consideration of the original treatment plan for the fractions with verification imaging.

Afterwards all plans were analysed and compared with each other regarding target coverage, sparing of organs at risk (OAR) and normal tissue complication probability (NTCP).

Results: Dose distributions and especially DVH show a deterioration of the target-coverage caused by the positioning inaccuracy. Deviations in dose at a single point can reach values of over 10 Gy. In single cases minimum plan agreement only achieved 66% pass within 3% local dose for the realistic case. Organs at risk and NTCP analysis result in a slightly better sparing of the rectum. Measures of quality like homogeneity and conformity differ just minimally regarding the different scenarios.

Conclusion: PTV-coverage suffers markedly by the positioning uncertainties, the shifted plans are in large parts clinically not acceptable. Surprisingly sparing of the OAR is not negatively affected by potential positioning errors for this prostate collective.

1. Background

While image-guided patient positioning before radiotherapy is by now standard in the clinical routine, the concrete operating procedures are still rather varied between different institutions. On the one hand, a plethora of imaging systems with different technical principles (photon energies, 2D vs. 3D imaging, etc.) are available; on the other, the frequency of set-up imaging (between daily and weekly) and the application of positioning corrections (on- vs. off-line, with or without action level protocols) depend on treatment indication, immobilization devices, and institution.

In principle, the necessary expansion margin between the clinical target volume (CTV) and planning target volume (PTV) to ensure good target coverage in the face of positioning uncertainties depends on the amount of positioning variability and can be calculated by a number of recipes if systematic and random set-up errors for a given scenario are determined [1–4]. However, most studies on the influence of positioning uncertainties on the dose distribution have hitherto relied on rather theoretical models of the average positioning errors and the resulting dose volume histograms (DVH's) [5–12]. The focus of this study is to apply this analysis to the clinical routine for a realistic patient collective on an individual basis.

For a collective of 40 patients treated for prostate cancer, the real set-up corrections performed after image-guidance were evaluated and the influence of these errors, had they not been corrected before treatment, was calculated using the real patient treatment plan. This allows for a precise comparison of the dose distribution deteriorated by set-up uncertainty with the original treatment plan, including the influence on dosimetric quality metrics, DVH parameters of PTV and organs at risk (OAR's), and normal tissue complication probability

* Corresponding authors.
E-mail addresses: katharina.bell@uks.eu (K. Bell), yvonne.dzierma@uks.eu (Y. Dzierma), melmor@web.de (M. Morlo), frank.nuesken@uks.eu (F. Nüsken), norbert.licht@uks.eu (N. Licht), Christian.ruebe@uks.eu (C. Rübe).

https://doi.org/10.1016/j.ejmp.2018.01.015
Received 23 August 2017; Received in revised form 22 January 2018; Accepted 24 January 2018

(NTCP). This provides a better evaluation of inter-patient variability and extreme effects which may be obliterated if only the average errors are taken into account.

2. Patients and methods

2.1. Patient collective, treatment and imaging

The patient collective consists of 40 patients treated for prostate cancer at our institution in 2013. All patients (after giving written informed consent) received a planning computed tomography (CT) at a Philips BigBore 120 kV CT. Immobilization is either performed using a KneeStep and FeetStep device or using a BlueBag vacuum cradle for improved stability and reproducibility.

Treatments were given in two series up to a total dose of 63–77 Gy (1.8–2.0 Gy daily). For the first series, the PTV included the prostate or prostate bed after surgery, seminal vesicles and the surrounding tissue of the small pelvis, and lymphatics if indicated. 21 of the 40 patients underwent surgery, 19 were radically treated with radiotherapy. For the second series (shrinking field, SF), the PTV was reduced for better sparing of the rectum. Treatment planning was carried out in the Philips Pinnacle treatment planning system (TPS) V9.0-9.6. The first series was planned either as a three-beam 3D conformal radiotherapy with 18MV photons or as intensity-modulated radiotherapy (IMRT) using 7–11 beams with 6MV photons; the second series was always given as IMRT. All plans were reviewed and accepted by at least two senior radiation oncologists before treatment.

Our institution has three energy-matched Siemens linacs with a 160 multi-leaf collimator, which differ mostly in the image-guidance systems. One Siemens Artiste offers kV imaging, two have a dedicated imaging beam line (IBL) [13,14], one only has 6 MV imaging; all can take planar or cone-beam CT (CBCT) images. At the linac, patients are positioned with the immobilization devices so that the room lasers are aligned with the temporary skin marks. Images are acquired as prescribed by the radiation oncologists and are compared with the digitally reconstructed radiographs or planning CT at the Siemens Syngo console. No action level is defined, so all necessary corrections are applied before treatment.

The patient collective presented here is an extended collective for which set-up corrections were retrospectively analyzed by reading out the couch shifts performed after imaging from the record-and-verify system. Results from a previous study focusing on set-up variability and possible differences between different imaging systems were published before [15]. In this collective, each patient received between 8 and 29 verification images (628 in total, Fig. 1), for a total of 1421 treatment fractions, which corresponds to about one image in every two fractions. The corrections ranged between −13 and 20 mm in anterior-posterior (AP), −19 and 19 mm in left-right (LR), and −10 to 17 mm in superior-inferior (SI) direction.

2.2. Simulation of shifted plans

To determine the influence of a set-up error on the dose distribution for each fraction, the isocenter of the treatment plan was shifted backwards on the planning CT to the position it would have been if no correction had been performed. This was carried out for each fraction with image-guidance. As the distribution of set-up errors is nearly Gaussian [15], we assume that the observed uncertainties were representative for those set-up errors that might have occurred unobserved on the days without imaging. We therefore simulate two scenarios:

1. An extreme case in which no image verification would be performed at all. Here, all shifted plans from the patient (i.e., one for each fraction with imaging, shifted back by the applied couch shift) were summed together and scaled up to achieve the final prescribed dose.
2. The realistic case, in which the shifted plans are weighted according to the frequency of fractions without imaging, and the original plan weighted according to the frequency of fractions with imaging, in which we assume that the performed corrections restored the originally planned dose distribution.

The original treatment plan is considered to be the gold standard, because this is the dose distribution that was planned and accepted for treatment. Neglecting the effect of anatomical changes in the patient, we can assume that the original plan corresponds to the dose distribution that would be delivered if daily imaging with corrections were performed. Hence, this plan serves for comparison against the two shifted plans.

The plan shifts were carried out in the Pinnacle TPS, however, the weighted summation of the fractions could not be performed here. Therefore, all dose distributions (together with CT and regions of interests) were exported in DICOM format and imported into the Matlab-based Computational Environment for Radiotherapy Research (CERR) [16] for further processing.

2.3. Dosimetric plan quality evaluation

In addition to the dose distributions and DVH metrics, the difference between the shifted plan and the original treatment plan is evaluated for each scenario. This gives a good impression on the number of points where dose deviations exceed a given level (e.g., 1%, 2%, 3%). In a way, this metric is similar to the gamma index pass rate, but disregarding the distance to agreement criteria (which would not make much sense when evaluating the effect of spatial shifts).

For the plan quality metrics, we consider the overdose rate (OR) and underdose rate (UR)

$$OR = \frac{TV_{PIV}}{PIV}$$

$$UR = \frac{TV_{PIV}}{TV}$$

where TV denotes the volume of the target, PIV is the volume receiving the prescribed dose, and TV_{PIV} is the volume of the target covered by the prescribed dose. Paddick's conformity index [17] is given by

$$CI = OR \cdot UR$$

All these metrics are evaluated for the shrinking field, as this receives the prescribed total dose and is most relevant for target coverage. Accordingly, the SF coverage is furthermore evaluated by the values V95% (percent volume of the SF that receives 95% of the prescribed dose). The homogeneity index is calculated as

$$HI = \frac{D2\% - D98\%}{D50\%}$$

where Dx% is the dose received by x% of the volume of the SF. For the organs at risk, the planning objectives are evaluated as given in Table 1.

2.4. Normal tissue complication probability

The NTCP was calculated in the Lyman-Kutcher-Burman model implemented in CERR with the following parametrization [18]:

$$NTCP = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{u} \exp\left(\frac{-t}{2}\right) dt$$

$$u = \frac{D - TD_{50}(V)}{m \cdot TD_{50}(V)}$$

with $TD_{50}(V) = TD_{50}(1)/V^n$

$TD_{50}(1)$ is the dose to the total organ which entails 50% complication risk, $TD_{50}(V)$ is the tolerance dose for a partial volume V, m is the slope of the sigmoidal curve, n describes the volume effect and D is the