A Strategy for the Use of Image-Guided Radiotherapy (IGRT) on Linear Accelerators and its Impact on Treatment Margins for Prostate Cancer Patients

Olaf Nairz, Florian Merz, Heinz Deutschmann, Peter Kopp, Helmut Schöller, Franz Zehentmayr, Karl Wurstbauer, Gerhard Kametriser, Felix Sedlmayer

Background and Purpose: In external beam radiotherapy of prostate cancer, the consideration of various systematic error types leads to wide treatment margins compromising normal tissue tolerance. We investigated if systematic set-up errors can be reduced by a set of initial image-guided radiotherapy (IGRT) sessions.

Patients and Methods: 27 patients received daily IGRT resulting in a set of 882 cone-beam computed tomographies (CBCTs). After matching to bony structures, we analyzed the dimensions of remaining systematic errors from zero up to six initial IGRT sessions and aimed at a restriction of daily IGRT for 10% of all patients. For threshold definition, we determined the standard deviations (SD) of the shift corrections and selected patients out of this range for daily image guidance. To calculate total treatment margins, we demanded for a cumulative clinical target volume (CTV) coverage of at least 95% of the specified dose in 90% of all patients.

Results: The gain of accuracy was largest during the first three IGRTs. In order to match precision and workload criteria, thresholds for the SD of the corrections of 3.5 mm, 2.0 mm and 4.5 mm in the left-right (L-R), cranial-caudal (C-C), and anterior-posterior (A-P) direction, respectively, were identified. Including all other error types, the total margins added to the CTV amounted to 8.6 mm in L-R, 10.4 mm in C-C, and 14.4 mm in A-P direction.

Conclusion: Only initially performed IGRT might be helpful for eliminating gross systematic errors especially after virtual simulation. However, even with daily IGRT performance, a substantial PTV margin reduction is only achievable by matching internal markers instead of bony anatomical structures.

Key Words: IGRT · Cone-beam CT · Setup errors · Safety margins · Prostate cancer

Eine Strategie zum Einsatz bildgeführter Radiotherapie an Linearbeschleunigern und ihr Einfluss auf Sicherheitsränder für Prostatakarzinompatienten

Hintergrund: Bei der Teletherapie des Prostatakarzinoms führt die Berücksichtigung verschiedener systematischer Fehler zu großen Sicherheitsrändern auf Kosten der Normalgewebetoleranz. Wir untersuchten, inwieweit systematische Lagerungsfehler durch initiale bildgeführte Radiotherapie (IGRT) reduziert werden können.

Patienten und Methodik: Es wurden 882 Cone-Beam-Comutertomographien (CBCT) von insgesamt 27 Patienten analysiert. Nach der Korrektur auf knöcherne Strukturen wurde das Ausmaß des Lagerungsfehlers als gemittelte Abweichungen nach null bis sechs CBCTs untersucht. Aus den Standardabweichungen (SD) der Verschiebungen wurden Schwellenwerte für maximal 10% aller Patienten definiert, die tägliche Bildführung erhalten sollten. Für die Berechnung der Sicherheitsräder für das Planzielvolumen (PTV) forderten wir eine mindestens 95%ige kumulative Dosisabdeckung des klinischen Zielvolumens bei 90% der Patienten.

Ergebnisse: Drei CBCT stellten den optimalen Kompromiss zwischen Arbeitsbelastung und erzielbarer Genauigkeit durch initiale Bildführung dar (Tabelle 1). Die Schwellenwerte für die SD, ab denen wir tägliche IGRT forderten, betrugen 3.5 mm in Links-rechts- (L-R-), 2.0 mm in kranial-kaudaler (C-C-) und 4.5 mm in anterior-posteriorer (A-P-)Richtung (Abbildung 1). Unter Berücksichtigung aller anderen Fehlertypen (Tabelle 2) wurden für das PTV kumulative Sicherheitsräder von L-R 8.6 mm, C-C 10.4 mm und A-P 14.4 mm ermittelt (Tabelle 3, Abbildung 2).

1University Clinic for Radiotherapy and Radio-Oncology, Landeskrankenhaus Salzburg, Paracelsus Medical University Salzburg, Austria,
2RadART – Institute for Research and Development on Advanced Radiation Technologies, Paracelsus Medical University Salzburg, Austria.

Received: March 5, 2008; accepted: August 14, 2008
Introduction
Due to the recent development of computed tomography (CT) imaging devices on linear accelerators image-guided radiotherapy (IGRT) became one of the most emerging fields of radiotherapy. High resolution images at the time of treatment, automatic registration and calculation of required shifts with respect to a planning CT provide the tools for utmost precision in patient positioning [9, 10, 17]. However, the process is time consuming and in clinical reality, a compromise between complexity of treatment and extensive workload has to be elaborated [5, 12, 14, 18–20].
Therefore, we developed a protocol for efficiently applying IGRT with an Elekta Synergy system for prostate cancer patients. The goal was to detect and minimize systematic errors, which might have been introduced at the time of planning and simulation, or in the first phase of the treatment process. Subsequently, patients who could not be positioned accurately enough to ensure adequate daily dose coverage of the target volume, should be identified and referred to ongoing image guidance.
We investigated the reduction of the systematic setup errors as a function of the number of IGRTs and determined decision rules for the application of cone-beam CT (CBCT).

Patients, Material and Methods
In 27 consecutive prostate cancer patients, a total of 882 sessions of image guidance by CBCT were recorded (27–37 CBCTs per patient). No standardised protocol for bladder and rectum filling was applied. Treatment was executed by a conformal four field technique in supine position. All patients underwent conventional simulation with skin marks drawn to indicate the isocenter. Prior to radiation, patients were first positioned according to their skin alignment, CBCTs were performed and the shifts to the planning CTs were calculated using the Elekta XVI software. Only translational shifts in the lateral, the longitudinal and the vertical direction were evaluated, rotational shifts were disregarded.
Since the patients in this study did not yet have internal marker seeds to allow for a manual match, we used the automatic grey value matching algorithm [8] but mostly achieved congruence of the pelvic bones only and not of the prostate itself. Therefore, a setup error correction was only possible for daily displacement between skin and bones and not for internal organ motion, which had to be taken into additional account for cumulative treatment margin definition.
Setup errors can be divided into systematic and random setup errors. The systematic setup errors, which are introduced at the time of treatment planning and simulation, can be reduced by calculating the average shift of consecutive treatments and by redrawing the skin marks at the mean position [1, 2], whereas random setup errors can only be corrected by daily image guidance.
In this retrospective study we investigated the achievable reduction of the systematic setup error as a function of the number of initial IGRT sessions during the first 6 treatment days. Additionally we wanted to detect those patients with the highest random setup errors (i.e. the highest standard deviation in consecutive positioning procedures), who had to be referred to daily image guidance, while for the others IGRT could be terminated after the initial sessions. The eventual necessity for the continuation of CBCTs was reviewed on a weekly basis. Considering average workload, we defined constraints to deliver daily IGRT to maximally 10% of all prostate patients by defining thresholds for the standard deviations (SD) in the three directions from the initial CBCT data. These threshold values had to be chosen carefully. On the one hand, a small value is desirable as it leads to smaller treatment margins, but will on the other hand cause more false negative results.

Results
For each patient, the mean shifts over all treatments were calculated and averaged over all patients. The resulting values were 0.00 cm in the left-right (L-R) direction, 0.00 cm in the cranial-caudal (C-C) direction and 0.07 cm in the anterior-posterior (A-P) direction with SD of 0.16 cm, 0.24 cm and 0.34 cm, respectively. The mean shifts give the remaining systematic setup error for the case of conventional simulation alone. Since the average shifts are zero or close to zero in all directions, no systematic errors in our treatment planning and simulation process could be detected [3]. Table 1 shows how the systematic error and its SD vary with the number of CBCTs involved. In the case of one CBCT it is assumed that the resulting shift is also applied to the skin marks, in the case of two to six CBCTs the average shifts are taken for the redrawing of the tattoos.
In a next step we considered the SD of the shifts for all patients. In order to comply with our requirement that not more than 10% of all prostate patients should receive daily IGRT we found the following thresholds: 0.35 cm in the L-R direction, 0.20 cm in the C-C direction and 0.45 cm in the A-P direction with 93%, 96% and 100% of all patients having values lower than the thresholds. One patient exceeded the threshold values in two directions, so overall 7% or two patients would...