Accuracy of out-of-field dose calculation of tomotherapy and cyberknife treatment planning systems: A dosimetric study

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Abstract

Purpose: *Late toxicities such as second cancer induction become more important as treatment outcome improves. Often the dose distribution calculated with a commercial treatment planning system (TPS) is used to estimate radiation carcinogenesis for the radiotherapy patient. However, for locations beyond the treatment field borders, the accuracy is not well known. The aim of this study was to perform detailed out-of-field-measurements for a typical radiotherapy treatment plan administered with a Cyberknife and a Tomotherapy machine and to compare the measurements to the predictions of the TPS.*

Materials and methods: *Individually calibrated thermoluminescent dosimeters were used to measure absorbed dose in an anthropomorphic phantom at 184 locations. The measured dose distributions from 6 MV intensity-modulated treatment beams for CyberKnife and TomoTherapy machines were compared to the dose calculations from the TPS.*

Results: *The TPS are underestimating the dose far away from the target volume. Quantitatively the Cyberknife underestimates the dose at 40 cm from the PTV border by a factor of 60, the Tomotherapy TPS by a factor of two. If a 50% dose uncertainty is accepted, the Cyberknife TPS can predict doses down to approximately 10 mGy/treatment Gy, the Tomotherapy-TPS down to 0.75 mGy/treatment Gy. The Cyberknife TPS can then be used up to 10 cm from the PTV border the Tomotherapy up to 35 cm.*

Dosimetrische Genauigkeit der peripheren Dosisberechnung für Tomotherapie und Cyberknife-Behandlungen

Zusammenfassung

Hintergrund: *Die Spätfolgen einer Strahlenbehandlung wie z.B. die Induktion von Zweittumoren werden umso wichtiger je besser das Behandlungsergebnis ausfällt. Oft wird die Dosisverteilung, welche mit einem kommerziellen Bestrahlungsplanungssystem (TPS) berechnet wurde, verwendet, um die Zweittumorinduktion für Strahlentherapie-Patienten abzuschätzen. Das Ziel dieser Studie ist es, detaillierte periphere Dosismessungen für einen typischen Strahlentherapie-Plan mit einem Cyberknife und einer Tomotherapie durchzuführen und die Messungen mit den Berechnungen des TPS zu vergleichen.*

Materialien und Methoden: *Individuell kalibrierte Thermolumineszenz-Dosimeter wurden verwendet, um absorbierte Dosis in einem anthropomorphen Phantom in 184 Punkten zu messen. Die gemessenen Dosisverteilungen von 6 MV intensitätsmodulierten Behandlungsfeldern für Cyberknife und Tomotherapie wurden mit den TPS-Dosisberechnungen verglichen.*

Resultate: *Für große Abstände vom Zielvolumen unterschätzen die TPS-Berechnungen die gemessene Dosis. Das Cyberknife-TPS unterschätzt die Dosis in 45 cm Distanz vom Isozentrum um einen Faktor 60, das*

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Conclusions: *We determined that the Cyberknife and Tomotherapy TPS underestimate substantially the doses far away from the treated volume. It is recommended not to use out-of-field doses from the Cyberknife TPS for applications like modeling of second cancer induction. The Tomotherapy TPS can be used up to 35 cm from the PTV border (for a 390 cm^3 large PTV).*

Keywords: Out-of-field-dose, treatment planning system, dose calculation, second cancer induction

Tomotherapie-TPS um den Faktor zwei. Bei Akzeptanz einer 50%-igen Dosisunsicherheit kann das Cyberknife-TPS minimale Dosen bis etwa 10 mGy/Behandlungs-Gy vorhersagen, das Tomotherapie-TPS ca. 0,75 mGy/Behandlungs-Gy. Das Cyberknife-TPS kann deshalb bis zu einer Distanz von ca. 10 cm zum PTV-Rand verwendet werden und die Tomotherapie bis zu ca. 35 cm.

Zusammenfassung: *Die Berechungen des Cyberknife- und des Tomotherapy-TPS unterschätzen periphere Dosen. Für die Abschätzung der Zweittumorinzidenz für die Cyberknife-Therapie sollte man sich nicht auf die vom TPS berechneten Dosen verlassen. Dosisberechnugen des Tomotherapy-TPS können bis zu einer Distanz von ca. 35 cm vom PTV-Rand verwendet werden (für ein 390 cm^3 großes PTV).*

Schlüsselwörter: Bestrahlungsplanungssystem, periphere Dosis, Dosisberechnung, Zweittumorinzidenz

Introduction

Radiation treatment modalities are steadily improved (intensity-modulated radiotherapy (IMRT), volumetric modulated arc therapy (VMAT), proton and heavy ion therapy, etc.). As a consequence, cancer cure rates have increased and it is expected that they will increase further in the future [1]. As a result, there are now many long term survivors of cancer who are at risk of late effects from therapy, including secondary cancers. These malignancies have been linked to chemotherapy as well as radiation exposure. It is estimated that more than 0.1% of the population between the ages of 16 and 44 are survivors of childhood cancer [2]. Hence the induction of second cancers can be an important side effect of radiation treatment and is currently under heavy investigation [3]. Sometimes the dose distribution calculated with a commercial treatment planning system (TPS) is used to estimate radiation carcinogenesis for the radiotherapy patient. In comparison to the deterministic effects in organs at risk with tolerance doses in the order of Gy or larger, the induction of second cancers can be important at low dose levels (∼ mGy) too. Commercial TPS, however, are designed to predict the dose distribution for planning a radiotherapy treatment. Therefore a TPS is commissioned to provide accurate dose distributions to judge the target dose and the dose to organs at risk (> ∼1 Gy). However, for locations beyond the treatment field borders, the accuracy is not well known. If TPS dose calculations are used as the input for second cancer induction calculations, the error of the calculated dose is one major uncertainty of the risk estimates [4,5].

The aim of this study was to perform detailed out-of-field-measurements for a typical pediatric radiotherapy treatment plan administered with a Cyberknife and a Tomotherapy machine (Accuray, Sunnyvale, CA, USA) and to compare the measurements to the predictions of the TPS. Howell et al. [6] have performed such a comparison for one commercial TPS (Varian Eclipse) up to a distance of 11 cm from the field edge. Taylor et al. [7] measured peripheral dose resulting from stereotactic radiotherapy and compared the measurements with iPlan calculations up to 40 cm from the field edges. Huang et al. [8] performed measurements of out-of-field doses for three different IMRT plans delivered with Varian Linacs and compared the results to Pinnacle3 treatment planning calculations. They found that the TPS underestimated the dose by an average of 50%. The goal of this study is to compare the accuracy of two other commercial TPS for distances up to 45 cm from the PTV border for intensity-modulated treatment delivery.

Materials and Methods

Treatment planning and delivery

The clinical treatment intention of this study was the curative irradiation of a rhabdomyosarcoma of the prostate for an adolescent patient, represented by an anthropomorphic phantom. The planning CT of the phantom and the contouring of the target structures and organs for the phantom were performed at one institution. The treatment was delivered as a simultaneous integrated boost. The large PTV had a size of 390 cm^3 and the boost PTV 195 cm^3. The dose prescription for the irradiation was 23 × 2.2 Gy for the Tomotherapy IMRT plan and 5 × 5.8 Gy for the Cyberknife plan. The fractionation schemes were matched to represent the same biological target dose. The dose constraints for organs at risk were adapted accordingly.