ORIGINAL PAPER

The technological basis for adaptive ion beam therapy at MedAustron: Status and outlook

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Abstract

The ratio of patients who need a treatment adaptation due to anatomical variations at least once during the treatment course is significantly higher in light ion beam therapy (LIBT) than in photon therapy. The ballistic behaviour of ion beams makes them more sensitive to changes. Hence, the delivery of LIBT has always been supported by state of art image guidance. On the contrary CBCT technology was adapted for LIBT quite late. Adaptive concepts are being implemented more frequently in photon therapy and also efficient workflows are needed for LIBT. The MedAustron Ion Beam Therapy Centre was designed to allow the clinical implementation of adaptive image-guided concepts. The aim of this paper is to describe the current status and the potential future use of the technology installed at MedAustron. Specifically addressed is the beam delivery system, the patient alignment system, the treatment planning system as well as the Record & Verify system. Finally, an outlook is given on how high quality X-ray imaging, MR image guidance, fast and automated treatment planning as well as in vivo range verification methods could be integrated.

Die technologische Basis für adaptive Ionenstrahltherapie bei MedAustron: Aktuelle Status und Ausblick

Zusammenfassung

In der Ionenstrahltherapie ist die Anzahl jener Patienten, die zumindest einmal während des Therapieverlaufes eine Anpassung des Bestrahlungsplanes aufgrund von anatomischen Veränderungen brauchen, höher, als in der Photonentherapie. Dies liegt an der Ballistik der Teilchenstrahlen und somit höheren Sensitivität auf Veränderungen. Deshalb wurde auch schon zu einem sehr frühen Zeitpunkt die Teilchentherapie täglich durch planare Bildgebung unterstützt. Es hat über lange Phasen jedoch kaum eine Weiterentwicklung dieser Technologie gegeben. Auch CBCTs zur bildgeführten Therapie kommen im Gegensatz zur Photonentherapie erst jetzt in den letzten Jahren standardmäßig zum Einsatz. Diese Technologie unterstützt mehr und mehr die Einbindung von effizienten, adaptiven Konzepten in der Photonentherapie und sind auch für die Teilchentherapie notwendig.

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MedAustron, ein Zentrum für Ionenstrahltherapie in Österreich, wurde dahingehend entwickelt, um die Integration einer effizienten, adaptiven Therapie zu ermöglichen. Ziel dieses Manuskriptes ist es, den aktuellen Status der Technologie bei MedAustron zu beschreiben und die potentielle Verwendung dieser Technologie für einen adaptiven Ansatz zu zeigen. Im Speziellen wird auf den Therapiebeschleuniger, den Robotertisch, den tischmontierten ImagingRing^{TM}, das Planungssystem und auf das Record & Verify System eingegangen. Zum Schluss werden potentielle Anwendungen von hochqualitativen Röntgenbildern, MR Bildgebung, schneller automatisierter Bestrahlungsplanung als auch in-vivo Dosismessungen erläutert.

Keywords: Light ion beam therapy, Radiotherapy, Adaptive

Schlüsselwörter: Ionenstrahltherapie, Strahlentherapie, Adaptive Therapie

1 Introduction

The physical characteristics of light ion beams and the resultant better conformity and dosimetric advantage over high-energy photon beams may lead to reduced toxicity and potentially provides the possibility for dose escalation to the tumour. Besides the ballistic selectivity there are biological advantages that depend on the used particle species. These physical and biological benefits can only be translated into clinically relevant advantages if treatment planning and dose delivery is based on state-of-the art technology for imaging, i.e. imaging for target definition and daily image guidance in- or outside the treatment room [1–3].

CT-based treatment planning was pioneered in the mid-70s by the Loma Linda University Medical Centre in California for the purpose of proton therapy and in-room image guidance for proton therapy was ahead of photon therapy in the 70s, 80s and 90s [4]. The picture in terms of advanced image guidance is different in today's radiotherapy setting. The leading role in image guidance in proton therapy several decades ago can be explained by the fact that the proton beam itself could not be used for imaging and consequently X-ray devices were applied for daily image guidance. Furthermore, the risk of missing the target due to the sharp distal dose fall off in combination with range uncertainties motivated daily set-up and anatomy verifications. Since the 1960s, the traditional method of aligning patients at a LIBT facility was based on orthogonal pairs of kV X-ray images that were obtained every fraction in the treatment room [4]. The technique generally used the patient's bony anatomy as alignment reference due to its relationship to the target volume and the critical tissues. More recently, also cone-beam CT (CBCT) technology has become available for image guidance in LIBT delivery [1,5]. Provided sufficient image quality is achieved, the soft tissue information can be of further value for image guidance of patients with tumours, which are not directly linked to bony anatomy [6].

During the last decade scanned ion beam delivery superseded passive scattering for LIBT. This further motivated image guidance in LIBT due to the pronounced sensitivity of the particle range to anatomical changes or setup errors [7]. However, this also leads to the dilemma that treatment adaptations due to anatomical changes are much more frequently needed than in photon therapy. Due to the anatomical changes, it is also difficult to track the actual delivered dose throughout the course of therapy. It is estimated that roughly one third of all LIBT patients require at least one re-planning during the course of their treatment. A process, which in LIBT still implies a lot of additional workload. Often the entire planning process from planning CT to patient specific QA needs to be repeated. Compared to the passive beam delivery, computerised treatment plan optimisation in scanned LIBT does not need to fabricate new passive elements, but re-planning requires comprehensive patient specific QA.

Adaptive concepts are being implemented more frequently in photon therapy [8] with still some additional workload. Highly innovative technology is therefore needed to allow faster and more precise treatment adaptations in the context of LIBT while reducing the overall workload. Within this manuscript, it is aimed to address the current status of the MedAustron LIBT centre and to highlight parts of its recent and future technology as well as visions to implement fast and precise treatment adaptation techniques.

2 Overview and current status of the technology installed at MedAustron

The MedAustron facility is a dual particle facility for proton and carbon ion beam therapy, which started its clinical operation with proton beams in one treatment room (see Fig. 1)