Physica Medica 54 (2018) 137–145

Contents lists available at ScienceDirect

Physica Medica

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

Original paper

Error detection during VMAT delivery using EPID-based 3D transit dosimetry

B. Mijnheer[a,*], A. Jomehzadeh[a,1], P. González[a], I. Olaciregui-Ruiz[a], R. Rozendaal[a], P. Shokrani[b], H. Spreeuw[a], R. Tielenburg[a], A. Mans[a]

[a] The Netherlands Cancer Institute, Department of Radiation Oncology, Plesmanlaan 121, 1066 CX Amsterdam, The Netherlands
[b] Department of Medical Physics, Isfahan University of Medical Science, Isfahan, Iran

ARTICLE INFO

Keywords:
EPID dosimetry
VMAT
Error detection
Quality assurance

ABSTRACT

Purpose: To investigate the effectiveness of an EPID-based 3D transit dosimetry system in detecting deliberately introduced errors during VMAT delivery.
Methods: An Alderson phantom was irradiated using four VMAT treatment plans (one prostate, two head-and-neck and one lung case) in which delivery, thickness and setup errors were introduced. EPID measurements were performed to reconstruct 3D dose distributions of "error" plans, which were compared with "no-error" plans using the mean gamma (γ_{mean}), near-maximum gamma ($\gamma_{1\%}$) and the difference in isocenter dose (ΔD_{isoc}) as metrics.
Results: Out of a total of 42 serious errors, the number of errors detected was 33 (79%), and 27 out of 30 (90%) if setup errors are not included. The system was able to pick up errors of 5 mm movement of a leaf bank, a wrong collimator rotation angle and a wrong photon beam energy. A change in phantom thickness of 1 cm was detected for all cases, while only for the head-and-neck plans a 2 cm horizontal and vertical shift of the phantom were alerted. A single leaf error of 5 mm could be detected for the lung plan only.
Conclusion: Although performed for a limited number of cases and error types, this study shows that EPID-based 3D transit dosimetry is able to detect a number of serious errors in dose delivery, leaf bank position and patient thickness during VMAT delivery. Errors in patient setup and single leaf position can only be detected in specific cases.

1. Introduction

Volumetric-modulated arc therapy (VMAT) has been introduced into radiotherapy (RT) practice mainly due to its capability to deliver a highly conformal dose distribution in a short time. However, there are many potential sources of error in a VMAT treatment, such as errors in the dose calculation by the treatment planning system (TPS), errors in the delivery of these complex treatments, and patient-related errors [1,2]. For this purpose, comprehensive quality assurance (QA) programs have been introduced that kept pace with these rapid advances in RT technology such as recently for VMAT [3]. In addition to QA programs of the separate components of RT equipment, patient-specific pre-treatment QA is often performed. Many methods have been explored to investigate the suitability of commercially available patient-specific pre-treatment dose verification systems for VMAT treatments by trying to detect deliberately introduced errors [4–6]. All studies have shown that different pre-treatment QA systems can detect different types of errors in VMAT delivery. The sensitivity of these systems for detecting the introduced errors depends on the characteristics of the plan as well as on the characteristics of the measurement system as discussed recently extensively elsewhere [7,8].

However, errors due to for instance anatomy changes in the patient, cannot be detected by means of pre-treatment QA. Therefore *in vivo* dosimetry is recommended as an additional method for patient-specific QA [9–11]. In a recent paper, it was shown that EPID-based *in vivo* transit dosimetry is one of the most promising methods in detecting incidents that had been reported clinically [12]. By means of EPID-based *in vivo* dosimetry a number of serious errors during 3D conformal radiotherapy [13,14] and IMRT and VMAT delivery [15–20] were discovered that would otherwise have gone undetected when only pre-treatment patient-specific QA would have been performed.

At The Netherlands Cancer Institute (NKI), EPID-based 3D *in vivo*

* Corresponding author.
E-mail address: b.mijnheer@nki.nl (B. Mijnheer).
[1] Present address: Department of Medical Physics, Kerman University of Medical Sciences, Kerman, Iran.

https://doi.org/10.1016/j.ejmp.2018.10.005
Received 16 May 2018; Received in revised form 14 September 2018; Accepted 2 October 2018

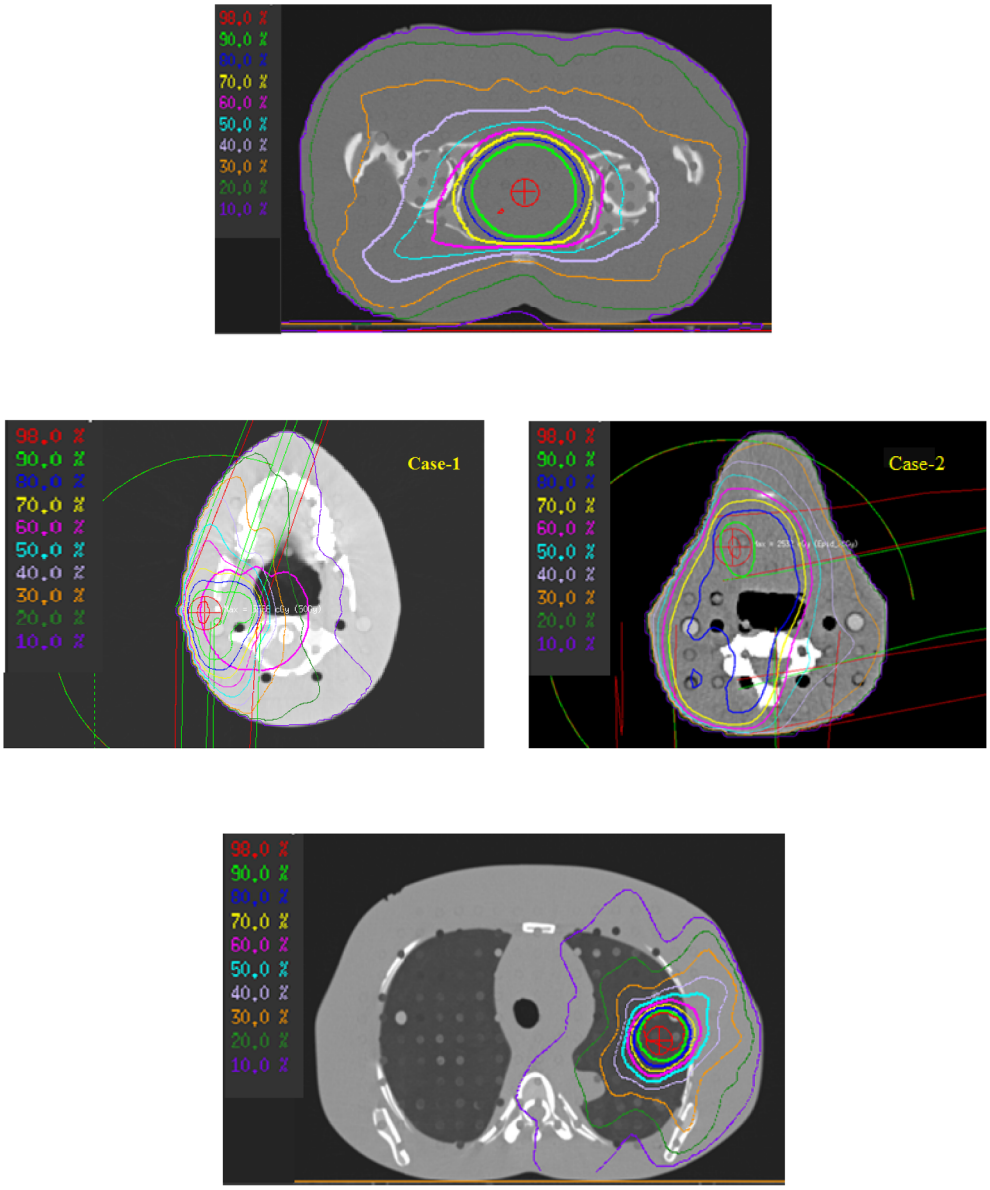

Fig. 1. Dose distributions in an axial plane of the Alderson phantom through the isocenter showing isodose lines of the four clinical plans. The position of the isocenter is indicated by the red crosshair. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

dosimetry is used for almost all IMRT/VMAT and 3D conformal radiotherapy (3D CRT) treatments. The method is based on a back-projection algorithm described in detail elsewhere [21,22]. Although 3D *in vivo* dose verification is used already for several years at NKI, limited quantitative information is available about the effectiveness in detecting clinically relevant errors. Only recently the sensitivity of this *in vivo* portal dosimetry system to various types of treatment parameter variations has been reported [23,24]. In the study of Bojechko and Ford [23] EPID measurements of 9 IMRT plans of a no-error situation as a baseline, were analyzed in 2D in the isocenter plane in combination with "error plans" created in a TPS. Their *in silico* investigation implicitly assumes 100% detectability of errors; i.e. a calculated error plan in combination with a no-error EPID measurement would yield the same result as an EPID measurement of an error plan. To be closer to the actual *in vivo* dose verification situation, Bedford *et al.* [24] performed a study with measured "error plans", determined with an EPID behind a phantom, i.e. a fully experimental approach. In that study, a previously developed 2D forward-projection method [25] and a 3D back-projection EPID dosimetry method have been compared for a cohort of 13 prostate VMAT patients [24]. Deliberate errors in the delivery of the treatment plan, which included an increase in monitor units and a shift in multileaf collimator opening, were investigated. Both in the study of Bojechko and Ford [23] and in the recent Bedford *et al.* [24] study, a 3D back-projection EPID dosimetry method almost identical to the one used at NKI was applied.

The first aim of this study is to investigate the effectiveness of our EPID-based 3D *in vivo* dosimetry method for error detection during VMAT treatments for a limited number of error types and treatment sites, using an anthropomorphic phantom. A second aim is to assess the appropriateness of the clinically used values for alert criteria in detecting these errors. Our study can be considered as an extension of the study of Bedford *et al.* [24].

2. Materials and methods

2.1. Accelerator, EPID and image acquisition

Measurements of VMAT irradiations were performed on various