Physica Medica 42 (2017) 157–161

Contents lists available at ScienceDirect

Physica Medica

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

Technical note

EPID-based in vivo dosimetry for stereotactic body radiotherapy of non-small cell lung tumors: Initial clinical experience

R. Consorti[a], A. Fidanzio[b,c,*], V. Brainovich[a], F. Mangiacotti[a], M. De Spirito[b,c], M.A. Mirri[d], A. Petrucci[a]

[a] Fisica Sanitaria ACO San Filippo Neri, Roma, Italy
[b] Istituto di Fisica, Università Cattolica del Sacro Cuore, Rome, Italy
[c] UOC di Fisica Sanitaria, Fondazione Policlinico Gemelli, Rome, Italy
[d] UOC di Radioterapia, San Filippo Neri Hospital, ASL Roma1, Rome, Italy

ARTICLE INFO

Keywords:
In vivo dosimetry
EPID
SBRT
Lung

ABSTRACT

Purpose: EPID-based in vivo dosimetry (IVD) has been implemented for stereotactic body radiotherapy treatments of non-small cell lung cancer to check both isocenter dose and the treatment reproducibility comparing EPID portal images.

Methods: 15 patients with lung tumors of small dimensions and treated with volumetric modulated arc therapy were enrolled for this initial experience. IVD tests supplied ratios R between in vivo reconstructed and planned isocenter doses. Moreover a γ-like analysis between daily EPID portal images and a reference one, in terms of percentage of points with γ-value smaller than 1, $P_{\gamma<1}$, and mean γ-values, γ_{mean}, using a local 3%–3 mm criteria, was adopted to check the treatment reproducibility. Tolerance levels of 5% for R ratio, $P_{\gamma<1}$ higher than 90% and γ_{mean} lower than 0.67 were adopted.

Results: A total of 160 EPID images, two images for each therapy session, were acquired during the treatment of the 15 patients. The overall mean of the R ratios was equal to 1.005 ± 0.014 (1 SD), with 96.9% of tests within ± 5%. The 2 D image γ-like analysis showed an overall γ_{mean} of 0.39 ± 0.12 with 96.1% of tests within the tolerance level, and an average $P_{\gamma<1}$ value equal to 96.4 ± 3.6% with 95.4% of tests with $P_{\gamma<1} > 90\%$. Paradigmatic discrepancies were observed in three patients: a set-up error and a patient morphological change were identified thanks to CBCT image analysis whereas the third discrepancy was not fully justified.

Conclusions: This procedure can provide improved patient safety as well as a first step to integrate IVD and CBCT dose recalculation.

1. Introduction

Accurate dose delivery is crucial for a stereotactic body radiotherapy (SBRT) that is hypo-fractionated in typically 3–8 delivery sessions with high doses to small regions [1]. Since the patient setup and the dosimetric accuracy must be high, over the last years multiple solutions have been studied to improve the correspondence between planned and actually delivered doses [1–4]. Pre-treatment verification tests for individual patients, are recommended by many radiotherapy organizations (e.g. ASTRO [5], AAPM [6], CPQR [7]), being justified by the increased complexity of the delivery techniques. However, pre-treatment Quality Control (QC) approaches are not able to detect on-treatment errors. For this reason various national and international organizations have recommended that each radiation therapy center should implement protocols for in vivo dosimetry (IVD) [8–10]. As a matter of fact in vivo dose measurements, to be compared with planned doses, can spot errors in patient setup, data transcription, beam delivery and anatomic changes that can lead to significant variations in dose delivery [11].

Amorphous silicon electronic portal imaging devices (aSi-EPID) have demonstrated unique favorable characteristics for IVD purposes, as high two-dimensional resolution and fast image acquisition [4].

In the last years, various methods have been implemented using commercial and homemade software to perform EPID based IVD in order to determine reference point doses or 2D and 3D dose distributions [12–16].

In particular EPID based IVD for lung tumors has shown to be a valuable tool for spotting patient's morphological changes such as atelectasis, tumor shrinkages [17] and shifts of the tumor position [1] leading to dose differences and deviations in tumor dose.

* Corresponding author at: Istituto di Fisica, Università Cattolica del Sacro Cuore, Rome, Italy.
E-mail address: andrea.fidanzio@unicatt.it (A. Fidanzio).

http://dx.doi.org/10.1016/j.ejmp.2017.09.133
Received 27 March 2017; Received in revised form 19 September 2017; Accepted 21 September 2017

The authors have recently implemented the commercial software SOFTDISO supplied by Best Medical Italy for IVD verification of Volumetric Modulated Arc Therapy (VMAT) irradiations. The software checks both isocenter dose and treatment reproducibility by γ-like analysis of EPID transit signals. Preliminary results on phantoms and patients have shown the feasibility and the sensitivity of this approach to detect dose discrepancies for pelvic and head & neck (H & N) treatments [18,19]. Comparable results were recently published by Ricketts et al. [20] and other groups [21,22], who developed a similar strategies for Epid-based IVD.

The aim of this paper is to report our current experience with EPID based IVD for SBRT of non-small cell lung cancer (NSCLC), also investigating the use of the CBCT to understand the causes of the detected discrepancies.

2. Materials and methods

2.1. Linac unit

In this work, a Varian linac Trilogy (Varian Medical Systems Inc, Palo Alto, CA), equipped with a cone beam CT scanner (CBCT) (OBI version 1.5.18.0) and operative at the San Filippo Neri hospital of Rome, was used for SBRT treatment delivery with a 6 MV X-ray beam. The linac multileaf collimator (MLC) consists of 120 leaves 0.5 cm wide at source to axis distance (SAD) while the electronic portal imaging device is an aS1000 EPID with a matrix of 1024 × 768 pixels, a pixel dimension of 0.392 × 0.392 mm^2 and a total sensitive area of about 40 × 30 cm^2. The source to EPID distance (SED) can vary between100 and 170 cm, but all the measurements reported in this work were obtained at a SED equal to 159 cm, as carried out in a previous work, where a generalized IVD procedure for static beams supplied by different types of linacs has been developed [15]. The SED equal to 159 cm was selected to allow gantry rotations without collisions with patient or couch. The limitation in filed size was about 20 × 20 cm^2, however in this work the field dimensions were small and all contained in the EPID active area.

The EPID was used in integrated image acquisition mode for all the measurements, i.e., the imaging started with beam-on and stopped when the beam turned off. The acquisition software was PV IAS3 version 7.5.02. All the images were stored as two-dimensional grayscale images whose values were averaged over all the subframes measured during the irradiation. The final image was automatically corrected for individual pixel sensitivity, dead pixels, and dark current by the acquisition software [23]. The images were exported as DICOM files to be analyzed by SOFTDISO. The EPID characterization in terms of signal linearity and reproducibility with MU and gantry angle has been assessed within ± 0.5% in agreement with that reported in a previous paper [16].

2.2. Planning strategy and patient's irradiation

For this study we selected 15 NSCLC patients treated in our clinic with SBRT in 2016. Treatment plans were created by RayStation V5.0 TPS (RaySearch Laboratories, Stockholm, Sweden) using a collapsed cone convolution algorithm with a grid size of 3 × 3 × 3 mm^3. This type of algorithm is suitable for calculating dose distributions of small fields and in density inhomogeneous regions [24].

For these patients a 4D CT scan was acquired and 4 inhale respiratory phases (0%, 25%, 50% and 75%) were registered to obtain the tumor-motion–encompassing volume used for delineation and treatment planning computation [25]. This way the amplitude of tumor motion is derived from the 4D CT scan and incorporated as a patient-specific margin in the internal target volume (ITV). The ITV to planning target volume (PTV) margin was fixed at 3 mm.

The treatment plans typically consisted of 2 arcs with starting and stop angles depending on the tumor location. The entire gantry rotation was described in the optimization process by a sequence of control points (CPs) every 3°. The collimator was set at 30° to minimize the tongue-and-groove cumulative effect. The irradiations were performed with 6 MV photon beam and 3 fractionation schedules: 3 × 10 Gy, 5 × 10 Gy and 5 × 8 Gy depending on tumor size and location following the protocol NCCN GL version 2.2013 [26].

The main planning objectives and constraints were: that at least 93% of the PTV received the prescribed dose; an underdosage of 10% to at maximum 1% of the PTV was allowed; the maximum PTV dose preferentially had to be between 110% and 120% and the volume of both lungs, excluding the GTV, that received more than 20 Gy (V20) was limited to 10%. SOFTDISO EPID dosimetry method is a measurement-based approach that uses correlation functions between the EPID signal and the dose in a water phantom, therefore it is not appropriate to reconstruct doses in lung tissue or in interface regions. However in this study the isocenter was always positioned inside the tumor, in a region with physical density close to water, to assure good accuracy for in vivo dose reconstruction in agreement with a previous publication [27]. Pretreatment verifications of all arcs were performed by means of ArchCheck phantom (Sun Nuclear Corporation, USA). VMAT plans were re-calculated and irradiated on that phantom to perform γ-analysis verification with passing criteria 3% (global)/3 mm and pass-rate of more than 90% of the dose points in the phantom should have a gamma value smaller than 1, (i.e. $P_{\gamma<1} > 90\%$).

An Extended Butterfly Armboard (Bionix, Toledo Ohaio USA) was used as a support for the patient setup for all the irradiations. Patient setup was checked before every treatment fraction by CBCT. Bony landmarks were used for defining positional variations respective to planning CT by means of a manual 3D-3D registration performed by a radiation oncologist. Deviations > 1 mm in the isocenter position were immediately corrected.

2.3. IVD and 2D treatment reproducibility checks

The mathematical aspects of the dose reconstruction algorithm are deeply explained in a previous paper [18]. Briefly, the algorithm is based on correlation functions between the EPID transit signal S_t and the measured dose in a solid water phantom along the beam central axis, where S_t is the EPID integral signal obtained as the average of 9 × 9 pixel values around the beam central axis (corresponding roughly to the TPS grid). For VMAT irradiations an overall correlation function, $C_{overall}$, is determined taking into account for each CP the equivalent field, patient radiological thickness, beam energy, isocenter depth, monitor unit number, coach attenuation and other factors [18]. This way the in vivo isocenter dose, D_{iso}, can be obtained by

$$D_{iso} = S_t \times C_{overall} \quad (1)$$

The accuracy of the correlation function based algorithm for lung irradiation was assessed in a previous paper in phantom and patient measurements [27].

The IVD checks were performed by the software package, SOFTDISO, described elsewhere [19], to obtain the isocentre dose, D_{iso}, and a γ-like analysis for the day-to-day EPID images. In particular propagating in quadrature the uncertainties (in two standard deviations) of the parameters in Eq. (1) (estimated in 4%) and the uncertainty of the $D_{iso,TPS}$ (estimated in 3%) the acceptance criteria for the ratio

$$R = D_{iso}/D_{iso,TPS} \quad (2)$$

resulted to $0.95 \le R \le 1.05$, i.e. a tolerance level of ± 5% was assumed for the R ratio.

For SBRT, most segments received 10–30 MU with a delivery time (1–4 s) of the order of the breathing period (3–5 s). Moreover, due to the spherical shape of PTVs, there were only a few segments with MLC leaves blocking part of the target in order to spare critical structures. The gantry usually rotated at reduced speed in order to complete