Physica Medica xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Physica Medica

journal homepage: http://www.physicamedica.com

Review paper

In vivo dosimetry for lung radiotherapy including SBRT

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ARTICLE INFO

Article history:
Received 2 February 2017
Received in Revised form 20 May 2017
Accepted 22 May 2017
Available online xxxx

Keywords:
In vivo dosimetry
Dose verification
Treatment verification
Lung SBRT

ABSTRACT

SBRT for lung cancer is being rapidly adopted as a treatment option in modern radiotherapy centres. This treatment is one of the most complex in common clinical use, requiring significant expertise and resources. It delivers a high dose per fraction (typically ~6–30 Gy/fraction) over few fractions. The complexity and high dose delivered in only a few fractions make powerful arguments for the application of *in vivo* dosimetry methods for these treatments to enhance patient safety. *In vivo* dosimetry is a group of techniques with a common objective – to estimate the dose delivered to the patient through a direct measurement of the treatment beam(s). In particular, methods employing an electronic portal imaging device have been intensely investigated over the past two decades. Treatment verification using *in vivo* dosimetry approaches has been shown to identify errors that would have been missed with other common quality assurance methods. With the addition of *in vivo* dosimetry to verify treatments, medical physicists and clinicians have a higher degree of confidence that the dose has been delivered to the patient as intended.

In this review, the technical aspects and challenges of *in vivo* dosimetry for lung SBRT will be presented, focusing on transit dosimetry applications using electronic portal imaging devices (EPIDs). Currently available solutions will be discussed and published clinical experiences, which are very limited to date, will be highlighted.

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http://dx.doi.org/10.1016/j.ejmp.2017.05.065
1120-1797/© 2017 Published by Elsevier Ltd on behalf of Associazione Italiana di Fisica Medica.

Please cite this article in press as: McCurdy , McCowan . *In vivo* dosimetry for lung radiotherapy including SBRT. Phys. Med. (2017), http://dx.doi.org/10.1016/j.ejmp.2017.05.065

1. Introduction

Stereotactic body radiation therapy (SBRT) for lung cancer is being rapidly adopted as a standard treatment option in modern radiotherapy centres. This treatment is one of the most complex in common clinical use, requiring significant expertise in respiratory motion management, 3D and/or 4D imaging in both pre-treatment and on-treatment settings, dose calculation algorithms, inverse treatment planning, IMRT and/or VMAT delivery techniques, and potentially deformable volumetric image registration. This complexity, combined with a high prescription dose per fraction (typically ~6–30 Gy/fraction), make powerful arguments for the application of *in vivo* dosimetry methods for these treatments. By estimating the dose delivered to the patient through a direct measurement of the treatment beam(s), ie. *in vivo* dosimetry, medical physicists and clinicians may have a much higher degree of confidence that the dose has been delivered to the patient as intended.

In vivo dosimetry is recognized and recommended by several international organizations (e.g. IAEA and WHO) as an important quality assurance tool [1–3]. And in some countries, for example Sweden, France, and the United Kingdom, *in vivo* dosimetry is included within national radiotherapy guidelines [4–6]. *In vivo* dosimetry is very powerful in that it can catch errors that many existing quality assurance (QA) techniques, including pre-treatment QA, will miss [7]. Analysis of incident reporting system data has quantitatively demonstrated that *in vivo* dosimetry is a highly effective addition to the common array of quality assurance techniques, providing a significant increase in error sensitivity, as well as being rated one of the most effective checks [8]. Mijnheer et al., Kron et al., and references therein provide recent and detailed overviews of *in vivo* dosimetry [7,9].

Much research effort has gone into developing and exploring *in vivo* dosimetry methods over the past two decades, mainly focusing on transit imaging approaches. In general, the measurement methods can be categorized as point-based measurements (ie. a single point dose measured with a diode, thermoluminescent dosimeter, MOSFET, or other point detector) or image-based measurements (ie. a megavoltage planar imaging system). Image-based measurements have the potential to provide much more information compared to point-based measurements. Image-based methods can be further classified into i) 2D image comparisons or ii) dose reconstruction methods. The 2D image comparison methods directly compare 2D measured transmission images to 2D predicted transmission images. In contrast, dose reconstruction methods make estimates of the actual delivered dose within a patient model, and these estimates can be 0D (a point), 2D (a plane), or 3D (a volumetric dose distribution). Most of the image-based methods can potentially be employed as a function of irradiation time to obtain time-resolved patient dosimetry information.

Note that several techniques presented in the literature utilize some real-time data acquired during treatment, but assume the treatment plan or some portion of the treatment plan is delivered exactly as intended and therefore for the purpose of this review are not considered fully *in vivo* dosimetry approaches. For example the MAASTRO group (The Netherlands) developed a method to estimate the 3D patient dose from non-transmission EPID images [10,11], which assumes the treatment plan is delivered faithfully. In their approach, EPID images of the delivered treatment fields are acquired without the patient present, and are converted to a water-equivalent portal dose image. This water-equivalent dose image is deconvolved with a dose deposition kernel, yielding an estimate of energy fluence, which is then back projected to a plane within the linear accelerator head. The patient dose is then calculated on a computed tomography (CT) or cone-beam CT (CBCT) model of the patient using XVMC [12] assuming that the incident photons are generated from a point-source at the linac focal spot location, with energy sampled from the energy fluence distribution derived from the non-transmission EPID field image(s). This method was demonstrated on four lung SBRT patients using megavoltage CBCT image data sets [13], while Persoon et al. presented 3D dose estimates for five example VMAT, non-SBRT patient cases using kilovoltage CBCT data sets [14]. In the latter study, treatment plans were modified in four out of five example cases, including one patient where significant changes in atelectasis were identified. Other groups are interested in dose estimates for lung tumours which account for the tumour motion. For example, lung tumour trajectories may be tracked with real-time planar imaging combined with automatic tumour segmentation techniques, and then the patient dose calculated for the tumour at its estimated position using the original treatment plan [15–17]. The estimated real-time lung tumour position can be obtained in other ways, for example via an external surrogate [18]. Lin et al. [19] used implanted fiducials to estimate lung tumour position in real-time, and also utilized real-time megavoltage transmission images to estimate MLC positions and extracted delivered monitor units as a function of time from linac log files, post-irradiation. That work also demonstrated that by considering the timing of the tumour position and the MLC positions, the interplay effect could be accounted for. While these foregoing approaches can be very useful applications for estimating dose within the tumour or patient for lung SBRT, for the purposes of this review, they are not considered fully *in vivo* dosimetry since they make assumptions regarding the reproducibility and accuracy of linear accelerator performance. There are also some commercial devices available that monitor entrance fluence to the patient (i.e. arrays mounted on the head of the linac, positioned below final collimation), but measurements with these devices do not include effects of real-time patient anatomy or position changes during the treatment, or immobilization devices, and thus are also not considered fully *in vivo* dosimetry for this review.

Currently only a handful of academic centres have substantial clinical experience implementing *in vivo* dosimetry programs, including for lung SBRT treatments. In-house developed software and (often) customized hardware is utilized. There are some commercial packages available including EPIgray (Dosisoft, Paris, France) and DISO (Università Cattolica S. Cuore, Rome, Italy) which perform single or few point *in vivo* dosimetry, as well as Dosimetry Check (Math Resolutions, Columbia, MD, USA) and recently iViewDose (Elekta AB, Stockholm, Sweden) both of which handle 3D *in vivo* dosimetry, although some limitations of the former have been reported [20]. As more commercial solutions become available, clinical experience with *in vivo* dosimetry for all disease sites will grow rapidly.

In this review, currently available solutions proposed in the literature for *in vivo* dosimetry, specifically those that have provided examples of lung radiation treatment or lung SBRT applications, will be presented. The few publications providing clinical *in vivo* dosimetry results for lung SBRT will also be summarized.

2. Rationale for *in vivo* dosimetry

The rationale for *in vivo* dosimetry of *any* disease site in radiotherapy is to catch errors that would otherwise be undetected. For lung SBRT, plan and anatomy complexity as well as large doses in fewer fractions, further increase the need for *in vivo* dosimetry for this patient population. By estimating the dose delivered to the patient through a direct measurement of the treatment beam(s), medical physicists and clinicians may have a much higher degree of confidence that the dose has been delivered as intended.

Please cite this article in press as: McCurdy , McCowan . *In vivo* dosimetry for lung radiotherapy including SBRT. Phys. Med. (2017), http://dx.doi.org/10.1016/j.ejmp.2017.05.065

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