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Review paper

The impact of technology on the changing practice of lung SBRT

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ABSTRACT

Stereotactic body radiotherapy (SBRT) for lung tumours has been gaining wide acceptance in lung cancer. Here, we review the technological evolution of SBRT delivery in lung cancer, from the first treatments using the stereotactic body frame in the 1990's to modern developments in image guidance and motion management. Finally, we discuss the impact of current technological approaches on the requirements for quality assurance as well as future technological developments.

1. Introduction

Radiotherapy has changed dramatically during the last decades, following advances in information technology and the wide progress in computer power and processing. Yet, there is a wide discrepancy in the distribution of technology not only between countries and institutions, but also among patient groups. Stereotactic body radiotherapy (SBRT) for lung tumours, also referred to as stereotactic ablative radiotherapy (SABR), is perhaps unique in the sense that it was originally targeted to patients with poor performance status (inoperable stage I lung cancer), but due to its success it is now gaining acceptance in operable patients. A large part of this success is attributable to technological advances in image guidance and motion management: increased precision in radiotherapy delivery enabled treatment of more challenging cases, which in turn meant that more patients became candidates for SBRT.

As the pool of patient candidates increases, the delivery of SBRT for lung cancer can no longer be limited to high-throughput academic centres. In this context, we observe the trend that SBRT is adopted by smaller and non-academic centres. We also observe that many technological solutions are available (see Table 1) and the investment in terms of equipment cost and human resources varies widely.

Lung SBRT is delivered in few fractions, typically 3–5. Hypofractionated treatment has benefits of preventing repopulation of neoplastic cells, a better cost effectiveness and is more convenient for patients compared to compared to conventional fractionation [1]. Bauman et al. [1] were the first to introduce the idea of cornerstones of SBRT in 2006; in a modern context these would be: 1) target localisation, 2) treatment planning and dose calculation, 3) hypofractionation and 4) motion management during treatment delivery. In this review, we aim to present the evolution of SBRT practice from the earliest clinical trials to today's practice. We will review the impact of the progressive technological advances on each cornerstone in terms of clinical workflow and patient outcome, where appropriate. In addition, we provide a discussion on patient selection and which technologies are, in today's perspective, considered a minimum standard ("must have") and which offer incremental improvements ("nice to have").

2. Target localization

Target localisation encompasses patient immobilisation, imaging for SBRT treatment planning, and in-room imaging for image guidance and verification. The choices made for each of these steps will have an impact on inter- and intra-fractional accuracy of dose delivery, and should be mirrored with appropriate treatment margins and a dose prescription level adapted to the target localisation method.

2.1. Patient immobilisation

Proper immobilisation permits reproducible positioning of the patient during the course of treatment, and is of crucial importance in highly precise treatments such as SBRT. Lax et al. developed a so-called stereotactic body frame enabling the first lung SBRT treatments [2]. This specially developed frame (see Fig. 1) served two purposes: it ensured the reproducible position of the patient through a head-to-

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Table 1
Selected technological approaches for lung SBRT, from early reports to more recent clinical trials.

Reference	Target localization	Motion assessment and management	Planning	Margins	Hot spot in PTV*	Prescribed dose/fraction‡	Dose calculation algorithm
Blomgren 1995 [8]	Stereotactic body-frame CT (repeated if necessary)	Fluoroscopy AC if motion > 1 cm	4–8 Non coplanar static beams	GTV-PTV 5 mm TR 10 mm CC	Aimed for 150%, achieved between 130 and 175%	Varied, 10–20 Gy in 1–3 fractions (minimum dose to PTV)	Type A (TMS, Helax)
Uematsu 2001 [22]	Daily verification using in room CT (slow scan) and X-ray simulator, coupled with external markers (FOCAL unit)	Patient trained to practice shallow breathing along with oxygen mask; AC if motion > 1 cm, measured with fluoro simulation	Multiple non coplanar arcs	GTV-PTV 5–10 mm	125%	50–60 Gy in 5–10 fractions, prescription point NS	not specified
Onishi 2004 [46]	In room CT on rails acquired in breath hold (repeated 3 times at planning session) Real time EPID acquisition (every 2 s)	Voluntary inspiration breath hold along with oxygen inhalation	10 non coplanar dynamic arcs	"ITV"-like approach based on the 3 repeated CT scans + 5 mm	Maximum 125%	6Gyx10 (2 daily fractions) to the "border of the PTV"	Type A (Focus, CMS)
Baumann2009 [63]	Stereotactic frame CT (repeated before each fraction if necessary)	Fluoroscopy AC if motion > 1 cm	5–9 beams	GTV-CTV 1–2 mm CTV-PTV 5–10 mm TR 10 mm CC	About 150%	15 Gy x3 to the periphery of the PTV	Type A with HC
Hurkmans 2009 [69]	4D CT (6–10 phases) or multiple slow CTs as alternative At treatment: online match on bony anatomy is minimum requirement kV-CT, MV-CT and orthogonal kV images are allowed	ITV or TAMP Gating, tracking, AC allowed, but not required.	7–13 beams Usually static, but dynamic arc allowed	ITV + 3–5 mm Or TAMP (min 3 mm,accounting for tumour motion) (larger margins if slow CT instead of 4D CT)	110% < hot spot < 140%	20Gyx3 for type A 18 Gyx3 for type B Prescribed so that 95% of PTV gets prescription dose, 99% of PTV gets 90% of prescription dose	Type A or B (with different dose prescriptions) HC: mandatory
RTOG 0618 [64]	Fiducials allowed in tumour Single 3D CT with contrast Daily orthogonal MV required as minimum IGRT	Gating, Breath hold, tracking, AC allowed but needs approval	"typically ≥ 10″ non-opposing fields, IMRT and dynamic arc allowed	GTV-PTV 5 mm TR 10 mm CC identical margins regardless of the technology used	110% < hot spot < 140%	20 Gyx3 prescribed "at edge of PTV"	HC is not allowed and must be turned off if available
Lambrecht 2016 [113]	4D CT required along with 3D or 4D PET/CT Volumetric image guidance system (2D images allowed for gating and tracking)	Gating, tracking or ITV	No requirement other than satisfaction of target and OAR constraints	ITV (if no tracking/gating) Institution-specific margins (verified by CBCT before/after each fraction)	110% < hot spot < 130%	7.5 Gyx8 Prescribed so that 95% of PTV gets prescription dose, 99% of PTV gets 90% of prescription dose	Type B required

Examples:
From Blomgren et al. [8], patient nr. 6 in Table 3: $hotspot = \frac{32Gy}{20Gy} = 160\%$

From Hurkmans et al. [69], following the prescription (i.e. no patient data): $hotspot = \frac{75Gy}{90\%\ of\ 60Gy} = 139\%$

* The hotspot was calculated as followed: $hotspot = \frac{maximumdosetoPTV}{minimumdosetoPTV}$ or $\frac{maximumdosetoPTV}{PTVencompassingisodose}$

‡ All doses are expressed as physical dose.