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Patient specific quality control for Stereotactic Ablative Body Radiotherapy (SABR): it takes more than one phantom

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Abstract. Stereotactic Ablative Body Radiotherapy (SABR) is an extension of the concepts of Stereotactic Radiosurgery from intracranial procedures to extracranial targets. This brings with it new technological challenges for set-up of a SABR program and continuing quality assurance. Compared with intracranial procedures SABR requires consideration of motion and inhomogeneities and has to deal with a much larger variety of targets ranging from lung to liver, kidney and bone. To meet many of the challenges virtually all advances in modern radiotherapy, such as Intensity Modulated and Image Guided Radiation Therapy (IMRT and IGRT) are used. Considering the few fractions and high doses per fraction delivered to complex targets it is not surprising that patient specific quality control is considered essential for safe delivery. Given the variety of targets and clinical scenarios we employ different strategies for different patients to ensure that the most important aspects of the treatment are appropriately tested, be it steep dose gradients, inhomogeneities or the delivery of dose in the presence of motion. The current paper reviews the different approaches and phantoms utilised at Peter MacCallum Cancer Centre for SABR QA.

1. Introduction

Stereotactic Ablative Body Radiotherapy (SABR) is a relatively novel approach to cancer treatment where very high doses per fraction are given to small lesions using image guidance and motion management. SABR has become an accepted treatment modality for early stage lung cancer [1] and an increasing number of other curative and palliative indications [2]. Compared to conventional radiotherapy SABR features a number of challenges that require consideration for quality assurance:

- Doses exceeding 10Gy per fraction
- Small and possibly dynamic radiation fields
- Non-coplanar beam arrangements
- Inhomogeneity correction
- Assessment of motion during planning
- Motion management during treatment
- High quality and frequent image guidance



1.1 Typical SABR scenarios

Based on the intracranial experience, the ‘classical’ SABR scenario is a small lesion located in a large parallel-organised critical structure such as lung and liver. Compared to conventional radiotherapy SABR dose distributions are often not homogenous with high dose regions exceeding 125% of prescription dose being not uncommon. Tight margins around the target are normal as image guidance allows for target localisation directly prior to treatment [3-7]. An extension of this concept is intrafraction monitoring of tumour location, which can either be done with radiobeacons [8, 9] or intrafraction kilovoltage monitoring (KIM) [10].

Figure 1 illustrates typical SABR scenarios. In the case of scenario a) the objective is to constrain the dose closely to the target and conformity indices become an important planning tool. The scenarios shown in figure 1b are emerging in clinical problems such as prostate SABR and the treatment of vertebral metastases on the left side of the figure and lesions close to intestines or other dose limiting structures on the right. Here steep dose gradients are important where for quality assurance spatial resolution becomes more important than absolute dose accuracy. Table 1 provides a summary of SABR scenarios and their specific challenges from a dosimetric point of view.

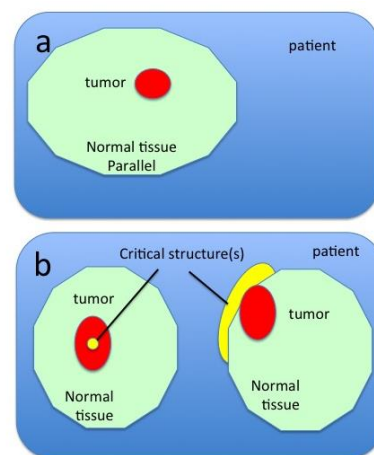


Figure 1. SABR scenarios a) ‘classical’ stereotactic problem, b) new SABR challenges

1.2. Patient specific quality assurance

Given these considerations SABR requires both machine and patient specific quality control (QC) activities to ensure SABR is delivered as planned. We report here on a suite of phantoms and QC approaches that were developed specifically for patient specific SABR QC at our institution.

2. Materials and Methods

A risk analysis was performed prior to commencing a SABR program for early stage lung cancer at Peter MacCallum Cancer Centre in 2009. As motion, small fields and inhomogeneity were considered key concerns, a Modus Quasar phantom which includes lung inhomogeneities was modified to allow for various motion patterns (figure 2) [11].

The phantom was used for individual patient QC in our institution [12] as well as credentialing of a clinical trial

of lung SABR (CHISEL, TROG 09.02). For the latter inhomogeneity correction was tested using small fields and the effect of motion was studied using radiochromic film [13]. It is well suited for assessment of dose distributions in coronal or sagittal plane as the cylinder holding dosimeters (right in figure 2b) can be rotated around a sup/inf axis. However, in some SABR applications the dose distribution in axial

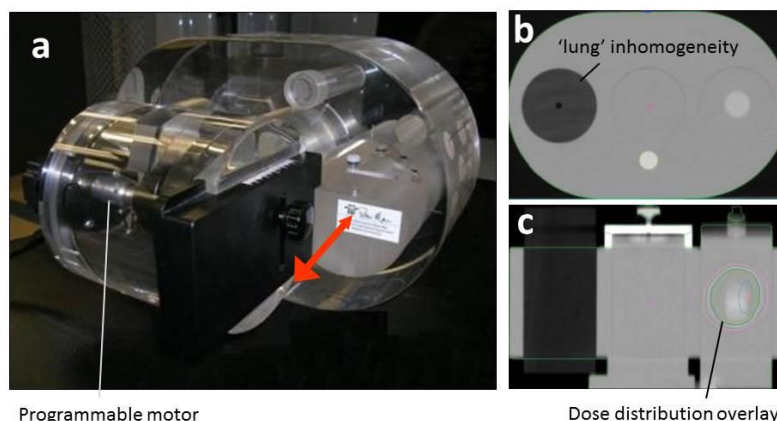


Figure 2. The modified QUASAR phantom (Modus Medical) featuring inhomogeneities and a programmable motor that allows mimicking customised motion patterns

plane is required to demonstrate the steep dose gradients between target dose and spinal cord and oesophagus. For this purpose we designed a phantom to mimic the body of a patient with the particular aim to verify the steep dose gradients encountered in SABR of vertebral lesions. This phantom is shown in figure 3.

Table 1. SABR applications and patient specific quality control activities

Treatment scenario	Main challenges	Planning considerations	QC approach, Phantom/dosimetry
Lung: early stage curative intent	Inhomogeneity, motion, small fields	Energy $\leq 10\text{MV}$, Field size $> 3 \times 3\text{cm}^2$, no VMAT FFF for single fraction	4DCT review, complex cases measure using QUASAR (Figure 2)
Lung: oligometastases	Inhomogeneity, motion, multiple lesions	As above, limitations on non-coplanar to limit overlap	As above
Liver	Motion, contrast CT, IGRT	Gating or breath hold considered	4DCT review, IGRT strategy review
Kidney	Motion, skin dose, IGRT	Consider 18MV, non-coplanar approach	4DCT review, in vivo dosimetry for skin
Bone metastases	Irregular size, close to skin (eg sternum)	Consider electron contribution	Consider in vivo dosimetry for skin
Vertebral body	Steep dose gradients required	IMRT > 9 fields VMAT	Phantom measurement using Rod (Figure 3)
Prostate	Irregular motion, urethra in centre	Fiducials common, spacers, rectal balloons	On-line imaging

Additional SABR Quality Control activities for individual patients depend on the scenario. Some important ones are listed in table 1. In addition to this we can utilise an independent dose calculation tool, Mobius 3D and FX. The latter relies on MLC dynalog files to determine dose distribution in the planning scan using a superposition convolution algorithm [14].

3. Results

While the introduction of motion did not alter the QC results in the phantom, the introduction of inhomogeneities as shown in figure 2, did. The initial measurements for individual patients confirmed that the Analytical Anisotropic Algorithm (AAA) used in the Varian Eclipse planning system has difficulties to predict the dose behind inhomogeneities accurately [15, 16]. After the initial phase of measurements this is now only verified using an independent monitor unit calculation and general checks of the treatment planning system.

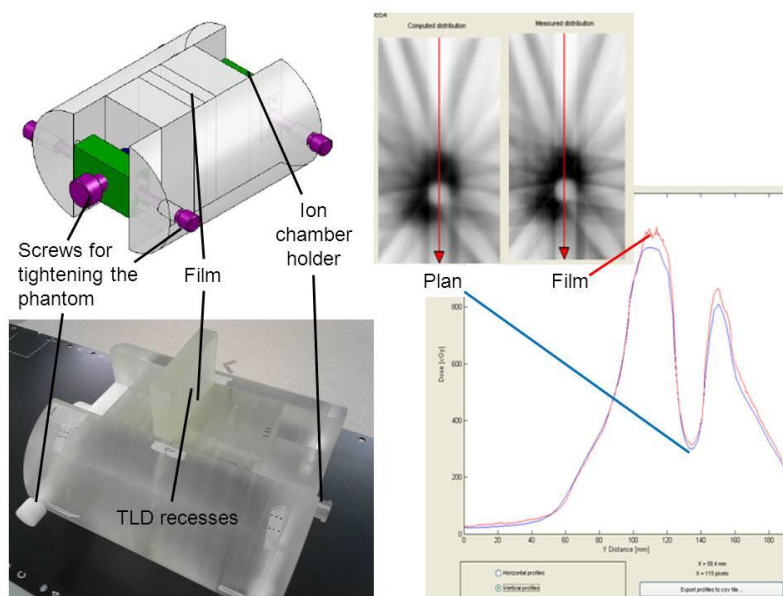


Figure 3. The ‘Rod’ phantom for SABR spine QA measurements. The evaluation relies largely on radiochromic film but can also include ion chambers and TLD measurements.

Given the fact that 3D conformal treatments could in general be verified without any significant problems once the treatment couch had been taken into consideration, patient specific QC activities have been reduced [12]. However, in the context of SABR for vertebral lesions, where Intensity Modulated Radiation Therapy is essential, every patient treatment is still verified using physical measurements prior to treatment. For this an ionisation chamber measurement and a radiochromic film assessment in the “Rod” phantom shown in figure 3 is routinely performed. It is particularly the dose distribution recorded on the film as shown in figure 3 on the right which informs the acceptability of the plan. The steep dose gradient in both plan and treatment verification film can be clearly seen and a 1mm distance to agreement criterion is typically used for evaluation.

4. Discussion and Conclusion

For the wide variety of SABR applications no single phantom appears to be suitable for individual patient QC as different treatment approaches require visualisation of dose distributions in different planes with high spatial resolution. In addition to ionisation chambers measurements radiochromic film was found to be essential for most of the measurements. Future work will be directed to studying real time dosimeters with high spatial resolution such as the dose magnifying glass [17] as replacement to shorten the turn around time for QC measurements.

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