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Lung SABR dosimetry

A national dosimetry audit for stereotactic ablative radiotherapy in lung

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ABSTRACT

Background and purpose: A UK national dosimetry audit was carried out to assess the accuracy of Stereotactic Ablative Body Radiotherapy (SABR) lung treatment delivery.

Methods and materials: This mail-based audit used an anthropomorphic thorax phantom containing nine alanine pellets positioned in the lung region for dosimetry, as well as EBT3 film in the axial plane for isodose comparison. Centres used their local planning protocol/technique, creating 27 SABR plans. A range of delivery techniques including conformal, volumetric modulated arc therapy (VMAT) and Cyberknife (CK) were used with six different calculation algorithms (collapsed cone, superposition, pencil-beam (PB), AAA, Acuros and Monte Carlo).

Results: The mean difference between measured and calculated dose (excluding PB results) was 0.4 ± 1.4% for alanine and 1.4 ± 3.4% for film. PB differences were −6.1% and −12.9% respectively. The median of the absolute maximum isodose-to-isodose distances was 3 mm (−6 mm to 7 mm) and 5 mm (−10 mm to +19 mm) for the 100% and 50% isodose lines respectively.

Conclusions: Alanine and film is an effective combination for verifying dosimetric and geometric accuracy. There were some differences across dose algorithms, and geometric accuracy was better for VMAT and CK compared with conformal techniques. The alanine dosimetry results showed that planned and delivered doses were within ±3.0% for 25/27 SABR plans.

Stereotactic Ablative Body Radiotherapy (SABR) aims to deliver a high dose of radiation in a few fractions (typically 3–8), often delivering more than 8 Gy per fraction, with high precision and accuracy. This approach has been shown to be effective for early-stage lung cancer patients, who are unfit for radical surgery, with improved local control and survival compared with conventional radiotherapy [1–3]. However, using a high dose per fraction to treat lung lesions poses significant challenges for accuracy both in calculation of dose in lung tissue and positioning of steep dose gradients.

Guidelines for the safe implementation of SABR are available from both national and international bodies [4–6]. In the UK, the SABR Consortium [3] advises radiotherapy centres to undergo an independent external audit of their SABR processes and in-house quality assurance within six months of commencing a SABR programme.

Previous dosimetry audits have investigated volumetric modulated arc therapy (VMAT) techniques [7], small photon fields [8] and SABR with flattening-filter free versus conventional flattening filter beams [9]. However there has not been a comprehensive dosimetry audit for SABR in the lung, which assesses the ability of a range of treatment planning systems (TPS) to accurately plan in inhomogeneous conditions and compares different delivery techniques.

A national lung SABR dosimetry audit was planned to assess the accuracy of treatment delivery. The aims were to make an independent check of safe implementation, identify problems in the modelling and delivery of each lung SABR technique, act as a pre-clinical independent check for centres starting lung SABR treatment and provide a snapshot of the range of delivery techniques and algorithms for treatment planning currently being practised. The audit was offered to both linac and CyberKnife™(CK) Synchrony® (Accuray Inc., Sunnyvale, CA) centres.

This work also provides baseline data for determination of appropriate tolerances for future audit and trials quality assurance (QA).

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Materials and methods

A postal audit was conducted, using the CIRS Model 002LFC IMRT thorax phantom (Supplementary Fig. 1), which has been used previously for a national dosimetry audit [10]. Participating centres were sent packs of dosimetry materials and instructions. EBT3 GafChromic film used for dose distribution analysis was provided by Clatterbridge Cancer Centre (CCC) (Bebington, UK), alanine dosimetry was provided by the National Physical Laboratory (NPL) (Teddington, UK) and coordinated from the Royal Surrey County Hospital (Guildford, UK).

Five CIRS thorax phantoms were borrowed and CT scans of each were intercompared to check for manufacturing consistency. No significant differences were found. The phantom consists of a water equivalent "body", with lung and spine regions which run continuously through the phantom. One half of the phantom contains holes (25 mm diameter) which can contain cylinders of different tissue equivalent materials. The left posterior lung hole was filled with a water equivalent insert. This setup represented the inhomogeneous densities of a water equivalent tumour (mean CT number – 12 Hounsfield Units (HU)), surrounded by low density lung (mean CT number – 772.9 HU).

A CT scan of the phantom was performed with 1.25 mm slice spacing and thickness and sent to each centre. A cylindrical internal target volume (ITV) (24.9 cm^3, diameter 2.5 cm, length 5.0 cm) was pre-delineated and contained the alanine pellets and film plane. The individual pellets were pre-delineated together with fiducials for use by CK users. For 96% of participating centres the uncertainty associated with differences in CT number to relative electron density and mass density calibration curves had previously been determined to be insignificant in the HU range from soft tissue to lung [11–13], for non-bone tissues. In this study the spine was treated as an organ at risk, limiting the dose entering through it and therefore the impact on uncertainty to dose to the tumour volume was assumed to be minimal.

In total 27 SABR treatment plans were measured. Planning systems, calculation algorithms and delivery techniques varied between the centres. Table 1 summarises the various combinations used by participating centres. All used 6 MV photon beams, except one using 10 MV.

Each centre grew their own planning target volume (PTV) from the ITV and created a plan for their PTV (average diameter 3.5 cm, length 6.0 cm) using their current clinical planning protocol/prescription dose. Field sizes varied depending on delivery technique.

Two dosimeters with complementary properties were chosen for the audit: alanine (from NPL) to provide accurate, small volume dosimetry at the target volume centre and EBT3 GafChromic film (Ashland, Covington, USA) to provide high resolution planar dosimetry, thereby measuring the dose coverage of the target volume and the surrounding dose fall-off in normal tissue. Both measurements correlate with clinically important parameters: dose at the PTV centre (tumour control probability) and dose coverage around the PTV (irradiation of surrounding tissue relates to normal tissue effects). High accuracy in dose prediction to the PTV does not necessarily mean that organ at risk (OAR) dose prediction is also accurate, so a simultaneous measurement using the two dosimeters was chosen to provide a thorough, clinically relevant and practical audit method.

Alanine: Calibration and dosimetry

In the insert rods for the five phantoms, the standard hole was for the NE2571 type Farmer chamber. Custom designed alanine pellet holders (0.8 mm thick wall) were made from polyether ether ketone (PEEK) which has a density of 1.4 g/cm^3 (Supplementary Fig. 1). These held nine pellets (each 2.3 mm thickness and 5 mm diameter) which were covered by the volume of measurement interest in the ITV. Three sets of loaded holders with a long detachable stem were sent to each centre, one for the reference dose measurement, one for the SABR plan dose measurement and a spare.

To reduce the uncertainty in dosimetry measurements with alanine pellets, a dose larger than 10 Gy is required [14]. The overall uncertainty associated with alanine dosimetry delivered during this audit ranges from 2.0 to 1.8% (10–24 Gy; k = 2) [14,15]. The reference dose measurement required each centre to irradiate a set of alanine positioned in blocks of local solid water at a dose of 10 Gy in local reference conditions. The calculated monitor units (MU) for a 10 cm × 10 cm field size, was first delivered to the local Farmer chamber to check the dose was as expected. This avoided irradiating the alanine with a wrong dose. The results of the alanine reference dose measurement were used for correction of the daily output.

GafChromic film: calibration and dosimetry

Centres were sent a sheet of GafChromic film with instructions for its labelling, cutting and use. Prescriptive labelling of the film prior to cutting ensured that the rotational/flip orientations of the calibration and plan measurement films were the same at scanning [16]. The film was cut to make four small calibration films, with a large piece remaining for the plan measurement. The calibration films were irradiated with a range of doses corresponding to approximately 120, 100, 70 and 50% of the dose of a single fraction of their prescription dose. The films were irradiated in the same conditions, on the same treatment unit as was used for the audit and were therefore effectively normalised for daily output (cGy/MU). The large piece of film was positioned in the axial plane between the two sections of the phantom, abutted by the lung surrounded water equivalent cylinder on one side and lung material on the other (Supplementary Fig. 1). Pins in the phantom, which were visible on CT images, pierced the film and facilitated the registration of measured and calculated dose distributions. All irradiated films were posted and stored in manila envelopes. Centres sent the calculated DICOM RT dose file and DICOM coordinates of

Table 1
Combinations of treatment planning systems, algorithms and treatment technique used.

Manufacturer	Treatment Planning System	Algorithm	Treatment Technique	No. of centres
Nucletron™, Netherlands	Oncentra® Masterplan	Collapsed Cone	Conformal	2
Varian Medical Systems, Palo Alto, CA	Eclipse™	AAA	VMAT	7
			Conformal	2
		Acuros	VMAT	1
Philips Healthcare, Best, Netherlands	Pinnacle®	Collapsed Cone	VMAT	3
			Conformal	2
Accuray Incorporated, Sunnyvale, CA	Multiplan®	Monte Carlo	CK	4
		PB		1
Elekta AB, Stockholm, Sweden	Monaco®	Monte Carlo	VMAT	4
	Xio	Superposition	Conformal	1