A comprehensive phantom with multi-detector inserts for pre-treatment quality assurance in stereotactic ablative radiotherapy

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Abstract. Stereotactic ablative radiotherapy (SABR) is an advanced high precision radiotherapy procedure where a high dose of radiation is delivered in a few fractions. Pre-treatment quality assurance (QA) is conducted prior to treatment to ensure the planned dose is delivered precisely. Several types of detectors have been explored for the use of pre-treatment QA in SABR. This study discusses the design of an in-house phantom with inserts designed to accommodate multiple detectors such as ion chambers, films, alanine, optically stimulated luminescence (OSLs), thermoluminescence dosimeter (TLDs), diodes, diamond detectors, and presage dosimeter. The study also presents some of the measurement results performed for selective treatment sites. The inserts were designed using Perspex and 3D printed materials. The Presage dosimeter provided a three-dimensional view of the delivered dose for SABR plans and matched closer to the planned dose. Most of the detectors/dosimeters explored in this study demonstrated measured results within 3% of the planned dose.

1. Introduction
Stereotactic Ablative Radiotherapy (SABR) also known as Stereotactic Body Radiotherapy (SBRT) is an advanced form of radiotherapy technique employed to deliver high doses of radiation in a small number of fractions, typically between one and five. Some of the salient features of SABR are a) less dose spillage b) high dose to ablate a tumour c) high precision and accurate dose delivery d) highly conformal e) aimed to improve overall survival and f) reduced overall treatment time. In the current era, SABR is extensively used in the treatment of the following sites: Lung, Liver, Spine, Kidney, Bone metastasis and Prostate. Figure 1 highlights the requirement of SBRT/SABR wherein precision (similar to stereotactic radiosurgery (SRS)) and image guidance are the key pillars of SABR technique. High dose of radiation delivered in a short period requires stringent quality assurance (QA) of the image guidance system and patient positioning systems. In addition to this, pre-treatment patient-specific quality assurance needs to be conducted prior to treatment delivery. Several guidelines have been published emphasising the importance of quality control and mandatory QA procedures conducted as part of the SABR treatment process [1-4]. Pre-treatment patient-specific quality assurance involves both absolute and relative dosimetry analogous to the QA conducted for intensity modulated radiation therapy (IMRT)/volumetric modulated radiation therapy (VMAT) [5, 6]. Several dosimeters have been proposed for patient-specific QA, among all, ionisation chamber and film are
considered to be the gold standard. Measurements could be classified as a) 1D or point dosimetry, b) 2D employing films, array detectors (ion chambers, diodes etc.), c) 3 dimensional, using gel/presage dosimeters [7-9] d) 4D use of 3D dimensional detectors simulating tumour movement. Though ionisation chambers are the gold standard, of late several other detectors including thermoluminescence detectors (TLD), alanine, optically stimulated luminescence dosimeters (OSL), diodes, diamond detectors, scintillation detectors etc., have been explored in radiotherapy.

In this study, we present an in-house phantom originally designed to house an ionisation chamber and films, which has been customised to accommodate multiple detectors such as TLD, alanine, OSL, diamond detectors, and presage 3D dosimeters for patient-specific QA of SABR/SBRT patients.

2. Materials and Methods

An in-house Perspex phantom known as Rod phantom was originally designed to accommodate a CC13 ionisation chamber. The Rod phantom mimics the shape of the thorax and has options to place films and TLDs in the transverse plane. The CC13 chamber enables the measurement of absolute dose. The relative dosimetry is obtained by using a film placed in the transverse plane. Figure 2a demonstrates an outline of the rod phantom and 2b shows the top view of the phantom with multiple slabs placed aside. Figure 2c shows a slab with embedded pins (highlighted in red ellipses) used to identify the orientation of the films and 2d exhibits the chamber entry port and the location of the film slab. Prior to performing patient-specific QA, chamber calibration is performed by exposing a known dose to the ionisation chamber at patient specific beam energy. Figure 3 illustrates the steps involved in patient-specific QA which involve exporting a SABR plan onto the rod phantom and then recalculating the dose. The dose measured on the linac is compared to the calculated dose.

At our centre, most of the SABR QAs are performed using the rod phantom which enables the physicists to acquire the absolute and relative dosimetry in one measurement. Multiple slabs in the phantom enabled us to explore other commercially available detectors. To accommodate these dosimeters inside the phantom, a Perspex slab with a circular hole as shown in Figure 4 b was designed to accommodate different tissue equivalent 3D printed inserts, Perspex concentric rings and Perspex spacers. The 3D inserts were designed in ViaCAD™ 2D/3D software, and output files were
exported in .stl format. The inserts were made of Acrylonitrile Butadiene Styrene (ABS) and printed using a CreateBot™ 3D printer.

Figure 3. Workflow of patient specific QA.

Alanine was one such dosimeter that has near tissue equivalence with very low energy dependence and possesses excellent isotropic response. Alanines used in this study have dimensions of 4.80±0.3mm by 3.00±0.3mm with 96% of alanine and 4% binder and are made at the Synergy Health (SH) and National Physical Laboratory (NPL). These dosimeters can be used between 10 Gy and 150 kGy with linear dose response up to 3kGy and are highly suitable for hypo-fractionated radiotherapy.

A second insert was printed to accommodate TLD 100H chips. The TLD 100H ((LiF: Mg, Cu, P) chips have an effective atomic number of 8.2 with a good linear response up to 10 Gy, less energy dependence as compared to TLD 100. The TLD 100H chips used in this study were of 3.2 mm x 3.2 mm x 0.89 mm in size.

Nanodots optically stimulated luminescence (OSL) are widely used in personnel dosimetry are gaining popularity in radiotherapy. The nanodot OSLs work on the same principle as that of the TLDs, except the nanodots have to be read with the aid of an optical light source/laser beam instead of heat. The Nanodot OSLs consists of a 4 mm diameter dot of aluminium oxide doped with Al2O3:C, housed inside a square package. A 3D ABS insert was printed on the 3D printer to accommodate the nanodot OSLs and the insert was placed inside the Perspex slab and stacked inside the rod phantom. The exposed nanodot OSLs were read in Microstar™ reader (Landauer®).

The PTW micro Diamond type 60019 is a small volume detector of 0.004 mm³ well suited for small field dosimetry with near tissue-equivalence property and negligible dose rate dependence. An insert
in Perspex was also designed for housing the Diamond detector, located in the same position as the CC13 ionization chamber.

The PRESAGE is a solid radiochromic 3D dosimeter widely used across a range of clinical applications [10-12]. It is composed of a transparent polyurethane matrix, Triarylmathane leuco dye and halogenated carbon radical initiators. It has several advantages over point dosimeters and even the commercially available 2D array detectors. The dose can be recorded in 3D space at a high resolution, and it is a lot easier to handle when it comes to measurement and insensitive to room light. Upon exposure to radiation, it undergoes a colour change which is highly dependent on the amount of exposed radiation. The presage dosimeters were prepared and poured into the cylindrical plastic container. Multiple Perspex slabs with circular holes were used to accommodate the Presage dosimeters. In this study, a maximum of 8 cm diameter Presage dosimeters were tested for SABR QA. Small Presage dosimeters could also be accommodated in this phantom by adding additional circular Perspex ring and spacers together. The images were processed in ImageJ software, and the dose maps were generated in PolyGeVero software.

SABR plans were generated in Eclipse™ treatment planning system (Varian Medical Systems) and verification plans were generated on the Rod phantom and transferred to linac for measurement. The phantom was positioned to the centre of target volume and measurement was made for all of the above mentioned detectors/dosimeters.

3. Results
Figure 5 shows the ratio of the ion chamber measurement results to planned dose. Non-SABR lung cases include spine, sternum and metastatic sites such as scapula, hip and ribs. Due to high dose gradients in complex SABR cases, some of the fields exceeds 3% but were within 5% of the field doses. The use of EBT3 films in rod phantom and the results have been demonstrated in our previous study [13] The results of alanine, TLD and nanodot OSLs showed very good agreement (<3%) with the Eclipse planning system.

![Figure 5](image)

**Figure 5.** Ion chamber results of 131 fields for SABR and non-SABR lung patients.

Figure 6 demonstrates the diamond results for a SABR spine patient proving the efficacy of the use of small sensitive volume for SABR QA. Presage dosimeter proved to be a valuable dosimeter for SABR QA to visualise the 3D dose distribution and moreover it is well suited for small fields as most of the optical CT scanners have some limitations with the size of Presage dosimeter used to acquire Optical CT scans.
4. Discussion
Pre-treatment SABR QA is an essential requirement in SABR treatment workflow that provides confidence in the accuracy of the planned dose before treatment delivery. Currently, there are several detectors/dosimeters available on the market. However, most of the detectors require specially designed phantom for measurements. In this study, we've exhibited a phantom that could accommodate most of the commercially available detectors and almost mimics the shape of the thorax. The phantom has been designed to reduce physics QA by performing both point dosimetry and 2D / 3D dosimetry simultaneously.

5. Conclusion
In this study, we demonstrated the design of a unique in-house phantom which could accommodate multiple detectors that include point dosimeters, 2D and 3D dosimeters. The phantom is quite robust, and our results demonstrate its use for performing both absolute and relative dosimetry for SABR patients.

6. References
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