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# A single centre evaluation of the 2019 UK SABR consortium guidelines for primary lung cancer: correlation between Prescription Dose Spillage and inverse Paddick Conformity Index

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## ABSTRACT

**Background:** The aim of the study was to determine level of agreement between RTOG Conformity Index (RTOG-CI), Paddick Conformity Index (PCI) and Prescription Dose Spillage (PDS) in describing lung stereotactic ablative radiotherapy (SABR) plan conformity; to elucidate any limitations, in practice, of PCI and PDS. International Commission on Radiation Units and Measurements report 91 (ICRU 91) aimed to reduce inconsistencies in dose prescription and normalisation between centres by specifying SABR reporting rules, and suggested using PCI. UK SABR Consortium 2019 guidelines adopted PDS to measure plan quality, but not the PCI.

**Materials and methods:** 51 consecutive lung SABR plans received 54 Gy in 3 fractions (54 Gy/3 Fr), 55 Gy/5 Fr or 60 Gy/8 Fr. Plans were developed according to 2016 UK SABR consortium guidelines, which did not specify PCI or PDS; these values were retrospectively calculated. As PCI varies from 0 to an optimum of 1, inverse PCI (invPCI) was used for calculations.

**Results:** PTV-adjusted PDS tolerances were met in 80.4% of studied plans. A near-perfect positive correlation between invPCI and PDS (R2 = 0.978) was found — stronger than between invPCI and the previously-used RTOG-CI (R2 = 0.915).

**Conclusions:** The strong invPCI-PDS correlation is likely dependent on adequate PTV coverage, present in our cohort. This supports the UK SABR Consortium's adoption of PDS provided PTV coverage is ensured. Plan conformity should be confirmed by visual slice-by-slice review.

**Key words:** SABR; lung cancer

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## Introduction

Stereotactic ablative radiotherapy (SABR) is an increasingly utilised treatment for patients with early-stage inoperable lung cancer. Due to the high precision of SABR, ablative doses can be given in hypofractionated regimens which maintain an acceptable quality of life for the patient [1]. Lung SABR fractionation is primarily determined by a tumour's proximity to organs at risk [2].

The wide variation in dose prescription and normalisation in lung SABR is well-recognised. The International Commission on Radiation Units and Measurements report 91 (ICRU) describes stan-

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**Table 1.** Formulae for calculation of studied metrics

| Metric | Formula |
|---|---|
| RTOG-CI | $V_{RI}/PTV$ |
| Inverse PCI | $1/[PTV_{PIV}^2/(PTV \times V_{RI})]$ |
| PDS | $V_{RI}/PTV_{PIV}$ |
| HI | $(D_{2\%}-D_{98\%}) \times 100/D_{50\%}$ |

RTOG-CI — RTOG Conformity Index; PCI — Paddick Conformity Index; PDS — Prescription Dose Spillage; HI — homogeneity index; PTV — planning target volume; $V_{RI}$ — volume encompassed by the prescription isodose; $PTV_{PIV}$ — PTV within prescription isodose; $D_{x\%}$ — the dose that receives the x% of the PTV

dards for the prescribing and recording of radiotherapy treatments, and potentially offers a means of standardisation between centres and countries.

The new ICRU Report 91 specifies reporting rules for SABR, and states that the high degree of dose homogeneity advised for other forms of radiotherapy should not apply to SABR [3]; this reflects not just acceptance of, but a desire for hot spots within the target volume as target dose inhomogeneity increases the dose conformity particularly for planning target volumes (PTVs) smaller than 40 cc [2]. Moreover, dose escalation appears to be important in the local control of the disease [4]; the hypothesized mechanism for this is enhanced elimination of radiation-resistant hypoxic cells within the tumour [5].

The RTOG-CI was proposed for stereotactic radiotherapy and was initially developed for use in brain lesions (see Tab. 1). RTOG-CI is defined as the ratio of the volume of prescription isodose to the PTV. With the widening of indications, this index was used to assess plans for other sites, including lung lesions [6] and until recently it was incorporated into UK SABR Consortium guidance. The RTOG-CI received criticism as "false-perfect" scores could be obtained if the target volume and prescription isodose volume are the same, even if they are different shapes or do not overlap. This problem is partially addressed in the 2019 UK SABR Consortium guidelines via introduction of the PDS [2], which is defined as the ratio of the volume of prescription isodose, to the volume of PTV within the prescription isodose and thereby requires overlap of PTV and prescription isodose for an optimal score. Consortium guidelines also introduced PTV-adjusted tolerances for the PDS.

An alternative conformity index was proposed by Paddick [7] which is defined as the product of an overtreatment ratio (defined by the ratio of the prescription isodose within the PTV, to the total prescription isodose volume) and an undertreatment ratio (defined by the ratio of the prescription isodose within the PTV, to the total PTV) and prevents false-perfect scores from being achieved. In practice, PCI and RTOG-CI often correlate closely provided the geometric overlap ratio (defined by the square of the prescription isodose within the PTV, divided by the square of the PTV) is 1. However, false-perfect scores cannot be achieved with the PCI; PDS may offer false perfect scores only if the prescription isodose lies entirely within the PTV but does not completely cover it. International Commission on Radiation Units and Measurements report 91 (ICRU 91) advises that conformity indices should be reported relative to the gross tumour volume (GTV), though accepts that for planning purposes it is useful to calculate relative to the PTV. PCI is quoted in the ICRU 91 but is not incorporated into the 2019 UK SABR Consortium's guidelines on conformity; we therefore sought to elucidate the relative benefits and drawbacks of each metric in clinical practice by analysis of our centre's lung SABR plans.

## Materials and methods

We collected data from 53 consecutive patients who were treated between March 2017 and December 2018 with SABR radiotherapy for non-small cell lung cancer according to 2016 UK SABR Consortium eligibility and planning guidelines [8]. Fractionation schedules were adapted according to risk. Two patients were excluded due to having atypical fractionation schedules (55 Gy in 8 fractions — 55 Gy/8 Fr — and 50Gy/8Fr); included patients were treated with 54 Gy/3 Fr, 55 Gy/5 Fr or 60 Gy/8 Fr.

A 4-dimensional planning CT scan was obtained for all patients using a Philips Brilliance CT Big Bore® 16-slice scanner (Philips Medical Systems, Best, Netherlands) with Wing Board. A GTV was outlined on maximum inhale and maximum exhale phases; these were compared and combined with maximum intensity projection outlines to generate an ITV. A cine loop confirmed that ITV covered the GTV on all phases. A margin of 5 mm axially and 6 mm superoinferiorly was added to generate a PTV. PTV dose was controlled using maximum, minimum and uniform dose constraints; both standard

and bespoke structures were used to constrain dose from normal tissue.

Planning optimisation was performed using the Pinnacle Treatment Planning System (Pinnacle ver. 9.10, Philips Healthcare, Eindhoven, Netherlands) using an adaptive convolve algorithm. In line with 2016 SABR Consortium guidelines [8] 95% of the PTV received 100% of the prescribed dose and the maximum dose to the PTV should be 110–140% of the prescribed dose. 99% of the PTV received a minimum of 90% of the fraction dose in all cases. An isotropic 2mm dose calculation grid was used for these calculations. For delivery, Elekta Agility machines (Elekta AB, Stockholm, Sweden) delivered coplanar volumetric modulated arc therapy with a 6MV flattened beam verified with XVI cone-beam CT (CBCT). A lung board and Kneefix® (Civco Medical Solutions, Coralville, IA) were used to immobilise and support the patient. 4D or 3D CBCT were used for verification depending on tumour motion.

Dose values to the PTV (D99% and D0.1 cc) were recorded for all plans[9]. Each metric displayed in Table 1 was calculated for all studied plans, and RTOG-CI and PDS were classified according to 2019 UK SABR Consortium guidelines as being within tolerance or constituting a minor or major deviation from protocol. Paddick, RTOG and PDS indices of conformity were correlated and $R^2$ values calculated to assess the strength of these correlations.

## Results

Fifty-one patients underwent tumour irradiation; none had synchronous tumours or sequential lesions treated during follow-up. Table 2 contains baseline characteristics for included patients. Patients were followed up for a median of 8.0 months (range: 0.2–21 months). At time of analysis there had been 9 deaths, 1 new lung primary and 1 patient with distant metastases.

**Table 2.** Baseline characteristics

| | |
|---|---|
| Age [median (interquartile range)] (years) | 76 (72–81) |
| Female : Male (%) | 59 : 41 |
| Tumour diameter [median (interquartile range)] (mm) | 19 (13–24) |
| PTV [median (interquartile range)] (cc) | 34.8 (21.2–47.2) |
| Histological diagnosis (%) | 14 (n = 7) |
| Fractionation schedule (%) | 54 Gy in 3 fractions: 5.9 (n = 3)<br>55 Gy in 5 fractions: 68.6 (n = 35)<br>60 Gy in 8 fractions: 25 (n = 13) |

PTV — planning target volume

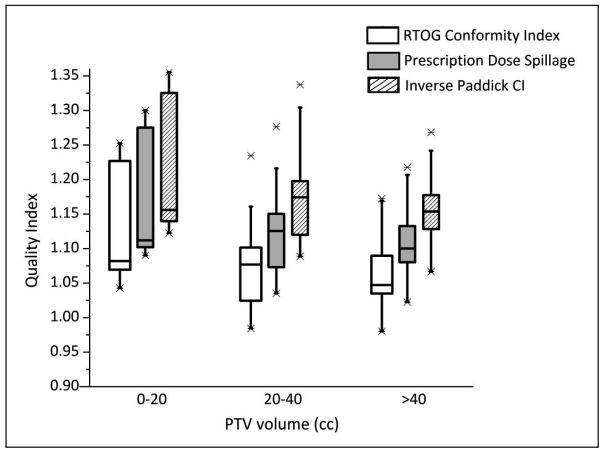


**Figure 1.** Conformity indices for the planning target volumes (PTVs) of < 20 cc (n = 10), 20–40 cc (n = 24) and > 40 cc (n = 17)

All plans were optimised according to 2016 UK SABR Consortium guidelines [8], while PDS and inverse PCI were calculated retrospectively. All plans generated were clinically acceptable and met the PTV coverage criteria: median dose (presented as % of the prescription dose) to 99% of the PTV was 96.8% (IQR: 95.9–97.8%), with a range from 93.7% to 103.8%. Figure 1 tabulates the distribution of RTOG-CI, Prescription Dose Spillage and Inverse Paddick Conformity index values for the PTVs of studied plans using box and whisker plots stratified by PTV volume (specifically 0–20 cc, 20–40 cc and > 40 cc). Table 3 displays compliance with UK SABR Consortium targets for RTOG-CI and Prescription Dose Spillage values. Retrospective calculation of Prescription Dose Spillage showed that 80.4% of all plans included in this study achieved the target conformity defined by 2019 UK SABR Consortium 2019 guidelines. However, 88.2% of plans were in RTOG-CI tolerance, with only 6 plans (11.8%) having an RTOG-CI minor deviation. Adjusted for volume, the following were within PDS tolerances: 70.0% (n = 7), 83.3% (n = 20) and 82.4% (n = 14) for PTV sizes of < 20 cc, 20–40 cc and > 40 cc, respectively. Two plans (3.9% overall, 11.8% of > 40 cc plans) had a major PDS deviation — both 5-fraction plans with PTV > 40 cc. 30% of the

**Table 3.** RTOG Conformity Index (RTOG-CI) and Prescription Dose Spillage (PDS) requirements and achievable numbers

| | UK SABR Consortium targets | | | | Studied patients | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Tolerance | | Minor deviation | | Within tolerance | | Minor deviation | | Major deviation | |
| | RTOG-CI[8] | PDS | RTOG-CI[8] | PDS | RTOG-CI | PDS | RTOG-CI | PDS | RTOG-CI | PDS |
| PTV < 20 cc | < 1.25 | < 1.25 | 1.25–1.40 | 1.25–1.40 | 100% (10) | 70.0% (7) | 0% | 30.0% (3) | 0% | 0% |
| PTV 20–40 cc | < 1.15 | < 1.20 | 1.15–1.25 | 1.20–1.30 | 87.5% (21) | 83.3% (20) | 12.5% (3) | 16.7% (4) | 0% | 0% |
| PTV > 40 cc | < 1.10 | < 1.15 | 1.10–1.20 | 1.15–1.20 | 82.4% (14) | 82.4% (14) | 17.6% (3) | 5.9% (1) | 0% | 11.8% (2) |
| All | | | | | 88.2% (45) | 80.4% (41) | 11.8% (6) | 15.7% (8) | 0% | 3.9% (2) |

SABR — stereotactic ablative radiotherapy

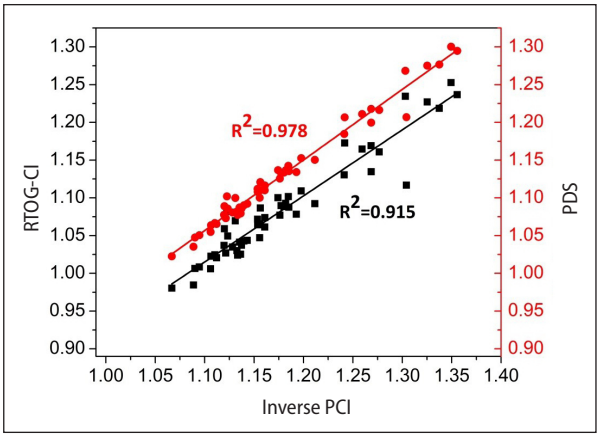


**Figure 2.** Relationship between RTOG-CI (bottom line, left-sided y axis), Prescription Dose Spillage (PDS) (top line, right-sided y axis) and Inverse Paddick Conformity Indices (PCIs) for the PTVs of studied plans

plans for PTV < 20cc showed minor deviation for PDS despite being in 100% tolerance for RTOG-CI.

The homogeneity index was 19.9 ± 4.8, 22.5 ± 4.2 and 23.5 ± 5.2 for PTV sizes of < 20 cc, 20–40 cc and > 40 cc, respectively, while the corresponding maximum PTV doses in terms of D0.1 cc were 122.2% ± 5.6%, 125.0% ± 5.6% and 125.1% ± 6.9%.

Figure 2 shows the correlation between values of the RTOG-CI and PDS with Inverse PCI for the PTVs of studied plans; $R^2$ for these correlations were 0.915 and 0.978, respectively.

## Discussion

Clinically acceptable plans, as defined by 2016 UK SABR Consortium guidelines, were achieved and delivered for all patients included in this study [8]. All PTVs met contemporaneous conformity tolerances apart from 6 PTVs with minor deviations; of these, 4 plans utilised the most conservative 60 Gy/8 Fr regimen, in line with tumour positioning close to the chest wall. Retrospective compliance with Consortium-defined PDS targets could be improved, with 19.6% of plans graded as having minor deviations or higher with regard to Consortium-defined targets, including 2 plans with a major deviation (both 5-fractions plans with PTV > 40 cc). On visual review, all 6 plans with minor RTOG-CI deviations (which includes both plans with major deviations from the PDS) were in close proximity to the high-density chest wall into which the dose is preferentially distributed.

In the present patient cohort, average PDS is higher than the average RTOG-CI for all PTV size categories (see Fig. 1). Indeed 2019 UK SABR Consortium tolerances for PDS are higher by 4.3% and by 4.5% compared with the RTOG-CI tolerances for the 20–40 cc and > 40 cc PTV categories, respectively. However, for the < 20 cc group, PDS and RTOG-CI tolerances are similar suggesting that RTOG-CI tolerance was lax and tighter conformity could be achieved. Our data supports this, with 30% of plans with PTVs < 20 cc showing minor PDS deviations despite 100% RTOG-CI compliance, unlike the larger PTV groups. Therefore, conformity may not have been pursued further once RTOG-CI criteria were met and there may have been potential for further improvement. Furthermore, values for homogeneity index and D0.1 cc were lower in PTVs < 20 cc than in the other categories; ideally inhomogeneity and high maximum doses would generate a steep peripheral dose drop-off and thereby improved conformity [10].

In the present study, a 6MV flattened beam was utilised for treatment planning. Unflattened beams are utilised by some centres for lung SABR treatment planning due to their physical characteristics and the shorter treatment times, though most of the published comparison studies find no significant

differences in target conformity [11, 12]. Pokhrel et al (2020) though reported that conformity for PTVs surrounded by low density lung was significantly better for 6 MV unflattened beams [13].

Our data demonstrates a near-perfect positive correlation between PDS and inverse PCI ($R^2 = 0.978$), a stronger correlation than between inverse PCI and the previously utilised RTOG-CI ($R^2 = 0.915$). Indeed, invPCI is directly related to PDS, with invPCI equivalent to PDS x (PTV/PTV$_{PIv}$). The second component of the PCI equation (PTV$_{PIV}$/PTV) is the target coverage and it is partially related to the ROTG-CI, as both metrics take into account the amount of PTV that is covered by the prescribed isode, however only RTOG-CI also accounts for the volume of normal tissue receiving the prescription dose [14]. This justifies the stronger correlation between invPCI and PDS than between invPCI and RTOG-CI.

PDS cannot accurately identify an under-dosed PTV since the PTV volume is not taken into account, thus this should be examined separately [15]. By comparison, undertreatment of the target would affect the PCI value but the PCI value itself would not indicate whether under- or over-treatment has occurred. However, under-coverage of the PTV can be assessed easily with the utilisation of parameters extracted from the dose-volume curve.

We accept as a limitation that our study only reviewed plans from a single centre — and that differences in practice between centres may make results less generalisable. Furthermore, the present study only included plans from before 2019 UK SABR Consortium guideline were adopted, which meant the impact of these guidelines on radiotherapy planning in clinical practice could not be assessed.

## Conclusions

Though the PDS cannot identify an under-dosed PTV, it accurately identifies overtreatment of normal tissue and in presence of adequate PTV coverage it effectively assesses conformity in lung SABR plans. As a one-figure composite measure of undertreatment and overtreatment PCI offers less direct utility than PDS, especially given the availability of other metrics for target undertreatment. PDS tolerances defined in 2019 UK SABR Consortium guidelines appear to push for higher conformity at lower PTV sizes, and our data suggest this is likely to be achievable. We caution the importance of reviewing plans visually slice-by-slice and not exclusively trusting metrics of conformity.

### Author contributions

S.G. — study concepts and design, literature search, data collection and analysis, manuscript preparation and editing; S.K. — data analysis, manuscript preparation and editing; R.N. — data analysis, manuscript editing; DY — guarantor of study integrity, study concepts and design, data analysis, manuscript preparation and editing; S.G., S.K., R.N., D.Y. — the authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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