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# Evaluation of improvements in plan quality with Photon Optimizer v16.1 for single brain lesion SRS treatment

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## ABSTRACT

**Background:** The purpose of this study is to compare the performance of the Photon Optimizer (PO) version 16.1 algorithm with its earlier version PO v13.6 and with Progressive Resolution Optimizer (PRO) version 13.6 algorithms.

**Materials and methods:** 20 patients with single brain lesions treated with the stereotactic radiosurgery (SRS) technique were retrospectively selected for this study. Initially, for all patients volumetric modulated arc therapy (VMAT) SRS plans were generated with the PRO v 13.6 algorithm. Then, all the plans were re-generated with two versions 13.6 and 16.1 of PO algorithm using the same setup and dose-volume optimization objectives as that of PRO with a similar planning approach. The quality of the generated plans was analysed using ICRU 91 plan evaluation parameters and also using dice similarity co-efficient (DSC), centre of mass distance (CMD) between target and prescription isodose line, Monitor units (MU) and brain-gross tumor volume (GTV) 12 Gy volume. Paired Student t-test was used for statistical analysis with 0.05 as a significant value.

**Results:** PO v16.1 improved all the dosimetric parameters studied compared to PO 13.6, the difference is statistically significant for all the parameters ($p < 0.05$), except for median dose and brain-GTV 12 Gy volume. PO v16.1 also showed statistically significant improvement for all the dosimetric parameters evaluated, except DSC and conformity index (CI), compared to PRO v13.6.

**Conclusion:** The PO v16.1 generated plans are dosimetrically superior to PO v13.6 and PRO v13.6 in terms of target dose coverage and dose gradient with lesser beam modulation and plan complexity for single brain lesion SRS.

**Key words:** external beam radiotherapy; stereotactic radiosurgery; Photon Optimizer; progressive resolution optimizer; VMAT

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## Introduction

Stereotactic radiosurgery (SRS) is a non-surgical therapy using radiation to treat functional abnormalities and smaller tumours of the brain. SRS technique involves the delivery of high radiation dose in a single fraction to the tumour with a sharp dose fall-off around the target, which helps to preserve healthy tissue. It has been proven that SRS provides superior or comparable treatment outcomes and is cost-effective compared to alternative conventional techniques [1–5]. Several SRS delivery techniques are available commercially [6–9], LINAC based SRS is one among them. Although several treatment delivery options are available within Linac-based stereotactic treatments, like non-coplanar three-dimensional conformal radiation therapy (3D-CRT), dynamic conformal arcs

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(DCA), intensity modulated radiation therapy, and volumetric modulated arc therapy (VMAT), VMAT is favoured due to its increased ability for dose shaping with minimal treatment time.

Intensity modulated techniques like IMRT and VMAT follow the inverse planning approach in which the prescription dose to the tumour and the organ at risk (OAR) dose constraints are given as input to the planning system in the form of dose-volume objectives which are then used by the optimization algorithms to form the objective function. The optimizer minimizes the objective function through iterative process modulating the intensities of radiation fields (either fixed fields as in case of IMRT or ARCs as in case of VMAT). The performance of the optimizer has a significant effect on the dosimetric quality and deliverability of the resulting treatment plans; hence, it should be carefully evaluated before adopting for clinical use. A new optimization algorithm called photon optimizer (PO) was introduced in Eclipse (Varian Medical Systems, Palo Alto, CA, USA) Treatment planning system (TPS) from version 13.5 as a substitution for the two old algorithms, that is Progressive Resolution Optimizer (PRO) for VMAT and Dose Volume Optimizer (DVO) for static field intensity-modulated radiotherapy (IMRT). The main difference between the PO and PRO algorithms is that instead of using a point cloud model where the sampling resolution varies within a structure and between structures for defining structures as in PRO, the PO algorithm implements a new structure model, where structures, DVH calculations, and dose sampling are defined spatially using a single matrix over the image. In PO fixed sampling resolution values (1.25 mm, 2. 5 mm, or 5 mm) are used for representing the structure during optimization. This resolution defines the planar X and Y pixel resolution in the slices, and the resolution orthogonal to the slices (Z resolution) is a function of chosen resolution and the slice spacing [10]. Very few studies compared the performance of PO and PRO [11–16], one among them is a phantom study [11], a couple of them are for conventional fractionation [12–13] and only few of them are for stereotactic treatments [14–16] out of which one compares the effectiveness of PO and PRO for multiple brain lesions [15]. In other two studies [14, 16] comparison of PO and PRO algorithms was made for a single lesion stereotactic treatments. The published results for the stereotactic and conventional treatment studies comparing PO and PRO are contradicting. For example Binny et al. [12] reported higher MLC modulation and MU with PO for non-stereotactic treatment involving larger target volumes, whereas Lie et al. [14] reported less MLC complexity and MU with PO for stereotactic treatment.

Many contradictions were noticed even for the single lesion stereotactic studies [14, 16]. Liu et al. have shown no statistically significant difference for any of the dosimetric parameters of target and OAR between PO v15 and PROv13.6, whereas Visak et al. have observed a significant difference for Gradient Index (GI) and OAR parameters between PO v13.6 and PRO v13.6 but they used two different versions of PO. These contradicting results highlight the need for further studies specific to disease site, tumor size and optimizer version to gain confidence for the effective use of PO. The purpose of this study is to compare the performance of the PO algorithm (version 16.1) with its earlier version 13.6 and with PRO (version 13.6) and to analyse whether changes are required in the optimization approach when progressing from algorithms PO v13.6 and PRO v13.6 to PO v16.1.

## Materials and methods

This retrospective analysis included 20 patients with single brain lesions treated with the SRS technique before the clinical implementation of PO (v16.1) in our institute. All patients underwent planning-CT scan with Philips Brilliance Big Bore CT scanner (Philips Medical Systems, Amsterdam, Netherlands) in a supine position, with the DSPS® (MacroMedics® Netherlands) mask and support, with a slice thickness of 1 mm. The mask consists of a double shell and is made up of a rigid thermoplastic material which provides anterior and posterior cranial support, minimizing the risk of inter and intra-fractional movements. The patients also underwent MR scans (Philips Medical Systems, Amsterdam, Netherlands) with a 1 mm slice thickness and a field of view large enough to include the entire surface of the patient. Post-contrast T1-weighted axial scans were acquired for all cases which were registered with the planning CT to define the gross tumour volume (GTV). The GTV was contoured with a high segment resolution in which the contour resolution is the same as the image resolution.

Keeping contour resolution the same as image resolution helps better adoption of actual tumour shape by contour for smaller lesions with dimensions of a few millimetres. The GTV was expanded by a 1 mm margin uniformly to form the PTV. The Gross Tumour Volume of the selected patients was ranging from 0.1 to 16.3 cc and the PTV volume varied from 0.6 to 29 cc. The prescription dose for the PTV varied from 12 to 21 Gy depending on the size and location of the PTV. Brain-GTV is the only critical structure considered for dose evaluation as in all the selected patients the lesions were away from other critical structures. The planning aim was to achieve at least 93% coverage of prescription dose for PTV with the steepest dose gradient possible around the PTV. Allowed dose heterogeneity within the PTV was up to 30%. Ring structures were created around the PTV to achieve conformal dose distribution. Initially, for all patients VMAT plans with 3–5 couch angles using 6 MV SRS photon beam of Trilogy LINAC (Varian Medical System, Palo Alto, CA) equipped with HD120 MLC were generated with the PRO algorithm using Eclipse Version 13.6. Two sets of beam arrangements were used in this study. For centralised tumours the beam arrangement includes two full arcs with a couch angle 15° and 345° and three half arcs with couch angles 45°, 90° and 315°, and for lateralized tumour the beam arrangements consists of four half arcs with couch angles 15°, 350°, 325° and 300° for right side tumours and 345°, 10°, 35° and 60° for left side tumours as shown in Figure 1, except for one patient with left side tumour for whom one half arc was removed to avoid beam entry through Cochlea and Eye ball and three half arcs were used with couch angles 0°, 30° and 60°. The AAA dose calculation algorithm was used for all plans with 1 mm dose calculation grid size to perform the final dose calculation. Then, all the plans were re-generated with two versions 13.6 and 16.1 of PO algorithms using the same setup and Dose-volume optimization objectives as that of PRO with a similar planning approach by the same planner to rule out the influence of external factors in the process of isolating the effect of optimizer model on the plan quality.

To compare the quality of generated plans, PTV median absorbed dose ($D_{50\%}$), near minimum dose (Dnear-Min), near maximum dose (Dnear-Max), conformity index (CI), gradient index (GI), and coverage percentage (C%) were calculated. Apart from this, the similarity between PTV and prescription isodose surface and skew of the dose distribution were analysed using parameters Dice similarity co-efficient (DSC) and Centre of Mass Distance (CMD) between target and prescription isodose line. MU is used as a measure of plan complexity. Brain-GTV 12 Gy volume was also analysed as OAR dose evaluation.

For Dnear-Min, Dnear-Max, Conformity Index (CI) and Gradient Index (GI), the ICRU 91 definitions were followed.

## The near-maximum dose ($D_{near\text{-}max}$)

For PTV With volume larger than or equal to 2 $cm^3$, the volume near-max represents 2% of the PTV, For PTV with volume lesser than 2 $cm^3$, near-max is an absolute volume of 35$mm^3$, in which case $D_{35mm^3}$ is reported.

## The near-minimum dose ($D_{near\text{-}min}$)

For PTV with volume larger than or equal to 2 $cm^3$, the volume near-min represents 98% of

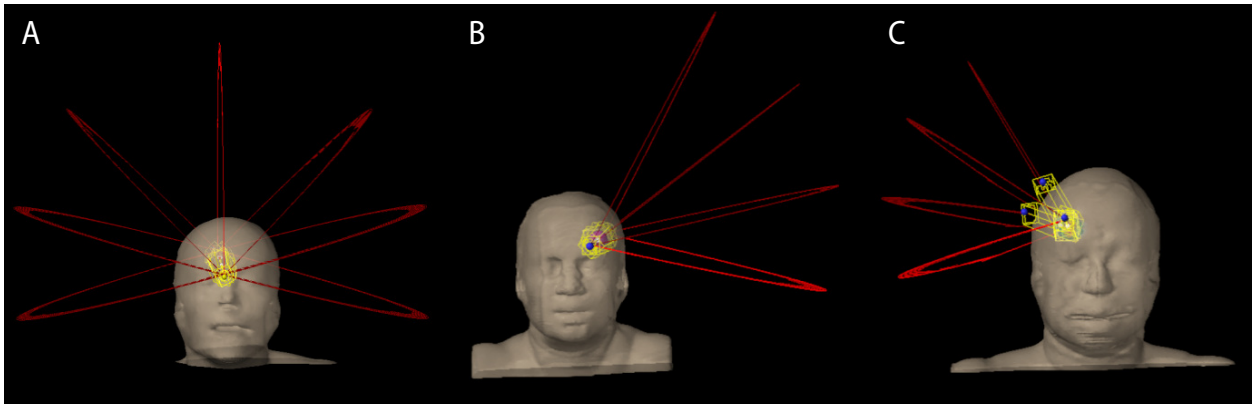


**Figure 1.** Arc geometry in 3D model view for: centralized tumour (**A**), left side tumour (**B**), right side tumour (**C**)

the PTV, For PTV with volume(V) less than 2 $cm^3$, near-min is an absolute volume of 35$mm^3$, in which case — $D_{V\text{-}35mm^3}$ is reported.

## Conformity index (CI)

$$Conformity\ Index\ = \frac{TV \times PIV}{\mathrm{PTV}^2_{\mathrm{PIV}}}$$

where TV is the target volume, PIV is the prescription isodose volume and $TV_{PIV}$ is the target volume within the prescription isodose volume.

## Gradient index (GI)

$$GI = \frac{PIV_{\mathrm{half}}}{PIV}$$

where $PIV_{half}$ represents the prescription isodose volume at half the prescription isodose.

The Dice similarity co-efficient (DSC) is defined as follows for this study:

$$Dice\ Similarity\ Co-efficient = \frac{2(PTV \cap PIV)}{PTV + PIV}$$

The dose and volume parameters for the calculation of various indices mentioned were calculated from the cumulative DVH. For the calculation of centre of mass of PIV the prescription isodose was converted to Dicom RT structure. The Eclipse Scripting Application Programming Interface (ESAPI) was used to generate PIV with high segment resolution using an in-house script as the default option available in Eclipse TPS for isodose to structure conversion employs only standard segment resolution in which the contour resolution is half of the image resolution that is 256 × 256 pixels when the image resolution is 512 × 512 pixels. The default resolution was not sufficient to adopt the shape of the prescription dose which is calculated with fine resolution. Statistical significance of the difference between the algorithms was tested using a two-tailed paired Student's *t*-test. In addition, the plans were divided into two groups based on beam arrangement (beam arrangements for centralized tumour and lateralized tumour) and two groups based on PTV volumes (volumes < 4cc and > 4cc). Multivariate analysis was carried out with MANOVA to study the correlation of the dosimetric difference among the algorithms with beam arrangement and PTV size. p-values < 0.05 were considered statistically significant.

# Results

The Mean values for all the parameters studied are presented in Table 1 for the three algorithms studied, PO v16.1, PO v13.6 and PRO v13.6, along with mean of the absolute difference and p values obtained using Student paired t-test for comparisons PO v16.1 *vs.* PO v13.6 and PO v16.1 *vs.* PRO v13.6. The distribution of data for each parameter studied is presented in the form of Box and Whisker chart in Figure 2 and Figure 3.

**Table 1.** Analysis of dosimetric parameters of plans generated with Photon Optimizer (PO) v16.1, PO v13.6 and Progressive Resolution Optimizer (PRO) v13.6 algorithms for single brain lesion stereotactic radiosurgery (SRS) treatment

| Parameter | Mean (SD) | | | Mean absolute difference (SD) | | p-value | |
|---|---|---|---|---|---|---|---|
| | PO 13.6 | PO 16.1 | PRO 13.6 | PO 16.1 *vs.* PO 13.6 | PO 16.1 *vs.* PRO 13.6 | PO 16.1 *vs.* PO 13.6 | PO 16.1 *vs.* PRO 13.6 |
| $D_{50\,\%}$ (%) | 118.01 (4.4) | 117.65 (3.6) | 118.62 (4.1) | 1.05 (1.35) | 1.24 (1.4) | 0.35 | 0.015 |
| Dnear-Min (%) | 97.76 (3.0) | 104.21 (3.2) | 102.36 (3.8) | 6.45 (2.78) | 2.04 (1.34) | < 0.001 | < 0.001 |
| Dnear-Max (%) | 127.96 (7.0) | 124.49 (5.6) | 127.00 (6.3) | 3.67 (2.78) | 2.71 (2.54) | < 0.001 | < 0.001 |
| CI | 1.22 (0.1) | 1.18 (0.1) | 1.14 (0.1) | 0.07 (0.04) | 0.05 (0.05) | 0.044 | 0.007 |
| GI | 3.30 (0.6) | 3.06 (0.5) | 3.21 (.5) | 0.25 (0.23) | 0.19 (0.15) | < 0.001 | 0.002 |
| C% | 95.92 (3.1) | 99.33 (0.9) | 98.43 (1.8) | 3.41 (2.62) | 0.9 (1.36) | < 0.001 | 0.008 |
| DSC | 0.91 (0.03) | 0.93 (0.03) | 0.94 (0.03) | 0.07 (0.02) | 0.01 (0.01) | < 0.001 | 0.131 |
| CMD [mm] | 0.08 (0.02) | 0.01 (0.01) | 0.02 (0.01) | 0.03 (0.02) | 0.01 (0.01) | < 0.001 | < 0.001 |
| Brain-GTV 12 Gy [cc] | 3.76 (2.7) | 3.74 (2.7) | 3.55 (2.8) | 0.18 (0.16) | 0.26 (0.29) | 0.666 | 0.022 |
| MU | 4435.35 (1097) | 3836.20 (752) | 4431.10 (1080) | 627 (514) | 645 (422) | < 0.001 | < 0.001 |

SD — standard deviation; Dnear-Min — near minimum Dose; Dnear-Max — near maximum dose; CI — conformity index; GI — gradient index; C% — Coverage percentage; DSC —dice similarity coefficient; CMD — centre of mass distance; MU — Monitor unit

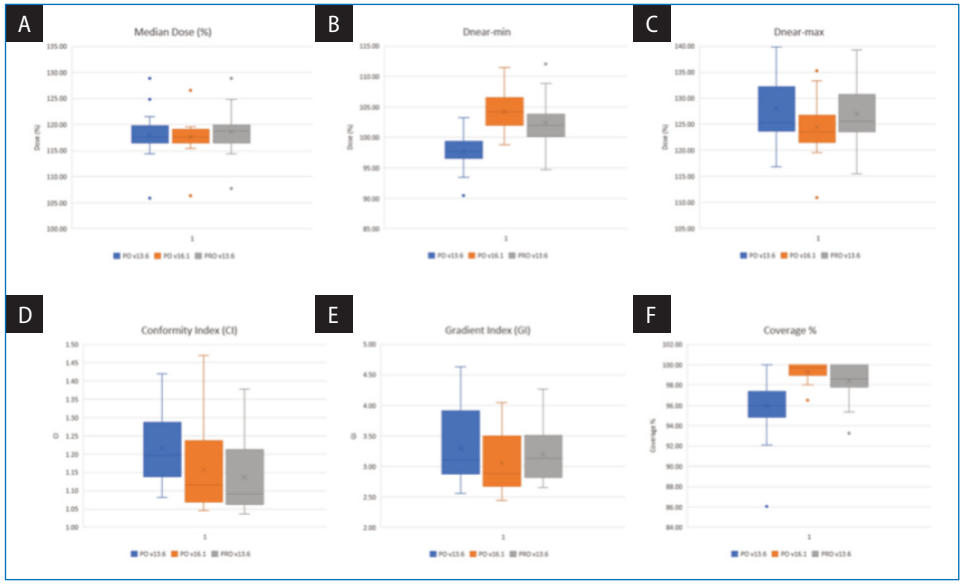


**Figure 2.** Box and Whisker Plots of dosimetry parameters for Photon Optimizer (PO) v13.6 (Blue), PO v16.1 (Orange) and Progressive Resolution Optimizer (PRO) v13.6 (Grey) algorithms. **A.** Median dose; **B.** $D_{near\text{-}min}$; **C.** $D_{near\text{-}max}$; **D.** Conformity index; **E.** Gradient index; **F.** Coverage %

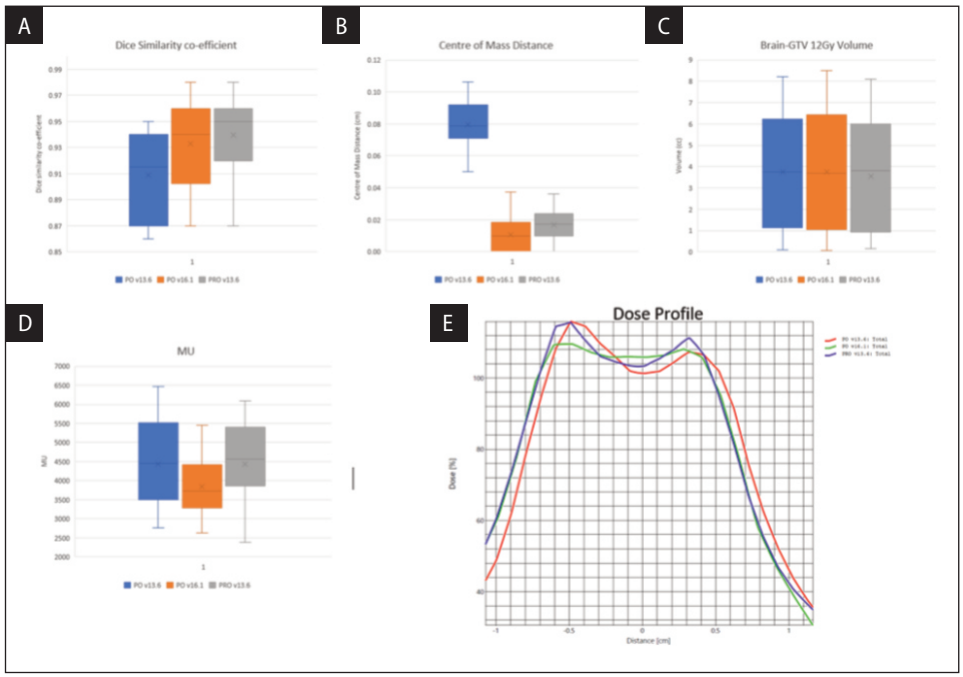


**Figure 3.** Box and Whisker Plots of dosimetry parameters for Photon Optimizer (PO) v13.6 (Blue), PO v16.1 (Orange) and Progressive Resolution Optimizer (PRO) v13.6 (Grey) algorithms. **A.** Dice similarity co-efficient; **B.** Centre of mass distance; **C.** Brain-gross tumor volume (GTV) 12 Gy Volume; **D.** Monitor Units (MU); **E.** Dose profile along X axis at Iso-centre for PO v13.6 (Red), PO v16.1 (Green), PRO v 13.6 (Blue)

PO v16.1 showed statistically significant improvement for all the dosimetric parameters calculated, except $D_{50\%}$ and Brain–GTV 12Gy compared to PO v13.6 as shown in Table 1. The mean difference of the parameters $D_{near\text{-}Min}$, $D_{near\text{-}Max}$, CI, GI, C%, DSC, CMD and MU between PO v16.1 and PO v13.6 were 6.45%, 3.67%, 0.07, 0.25, 3.41%, 0.03, 0.07 cm and 627MU, respectively, with p val-

ues < 0.001 for all the parameters indicating very significant difference, except for CI for which the p value is 0.04. The mean difference of $D_{50\%}$ and Brain–GTV 12Gy between PO v16.1 and PO v13.6 were 1.05% and 0.18 cc with p values of 0.35 and 0.67, respectively.

There was a significant difference between PO v16.1 and PRO v13.6 for all the parameters analysed, except DSC. The mean difference of the parameters $D_{50\%}$, $D_{near\text{-}Min}$, $D_{near\text{-}Max}$, CI, GI, C%, CMD, MU and Brain–GTV 12Gy were 1.24%, 2.0%, 2.7%, 0.05, 0.19, 0.9%, 0.01 cm, 644 MU and 0.26 cc with the corresponding p values of 0.01, < 0.001, < 0.001, 0.007, 0.002, 0.008, < 0.001, < 0.001 and 0.02, respectively. The mean difference of DCS between PO v16.1 and PRO v13.6 was 0.01 with a p-value of 0.13.

The MANOVA analysis showed that the difference in the improvement of dosimetric parameters with PO v16.1 over the other two algorithms between the two beam arrangement groups and between the two PTV volume groups was statistically insignificant with Wilk's Lambda and Pillai Trace p values > 0.05, except for CI. There was no significant difference in CI improvement with PO v16.1 between the beam arrangement groups but there was a significant improvement in CI difference (p = 0.001) between PO v16.1 and PO v13.6 for the < 4 cc PTV group compared to the > 4 cc PTV group.

## Discussion

Eclipse stopped providing PRO optimizer from Eclipse v16.1 onwards and the users are provided only with PO for IMRT and VMAT plan optimization. Hence, the understanding of the difference between PRO and PO is of paramount importance for smooth transition planning skills from PRO to PO algorithm. The PO was released for clinical practice in Eclipse v13.5 and is improved over the versions released. The improvements in Eclipse v16.1 compared to version 13.6, which may influence the optimizer performance includes but is not limited to, enhancement in the voxel based structure model to improve the structure resolution in Optimizer, change in Multi Resolution Dose Calculation (MRDC) resolution, improved tongue and grove modelling, new optimizer dose calculation engine called Fourier Transform Dose Calculation (FTDC) for GPU based calculation and an option to choose target projection margin [17, 18]. Hence, there is a need to compare the performance of the latest version available for practice when moving from its earlier versions. This study is designed considering these two points. The optimizers were compared in terms of coverage, conformity, dose gradient, skew of dose distribution, normal tissue dose and plan complexity.

The dose coverage improved with PO v16.1 considerably for the same dose volume objective compared to PO v13.6 and PRO v13.6 which is demonstrated by the higher mean values of dose coverage percentage and $D_{near\text{-}min}$ for PO v16.1 compared to the other two algorithms. Also, the use of PO v16.1 resulted in significantly lesser hot volume. Significant improvement in the parameters $D_{near\text{-}Min}$ and $D_{near\text{-}Max}$ without much change in $D_{50\%}$ (indicated by higher p-value of 0.35) for PO v16.1 compared to PO v13.6 indicates that PO v16.1 improves the coverage and controls the hotspot by enhancing the dose distribution in the low and high dose regions of the PTV keeping the median dose region intact. The other two studies [14, 16] comparing PO and PRO for stereotactic treatments normalized the dose distribution of PO and PRO to have the same coverage but in this study the normalization is avoided to analyse if any modification in optimization objective is required when progressing from PO v13.6 and PRO v13.6 to PO v16.1.

The conformity and dose gradient is very crucial for Stereotactic treatments as it involves the delivery of very higher dose per fraction, PO 16.1 achieved better conformity than PO13.6 but statistically inferior to PRO 13.6. This outcome contradicts the observation made by Liu et al. [14] where it was observed that there was no significant difference in CI between PO v15 and PRO v13.6. The lesser CI of PO v16.1 compared to PRO v13.6 plans may attributed to the improved dose coverage achieved by PO v16.1. The dose gradient index achieved with POv16.1 is superior to PO v13.6 and PRO v13.6 indicating comparatively sharper dose falloff. The higher dose gradient and dose coverage with PO v16.1 compared to PRO v13.6 shadows its inferior CI.

The DSC and CMD results show skewed dose distribution with PO v13.6 with a centre of the mass shift of around 1mm which is clinically very significant, particularly for stereotactic treatments in-

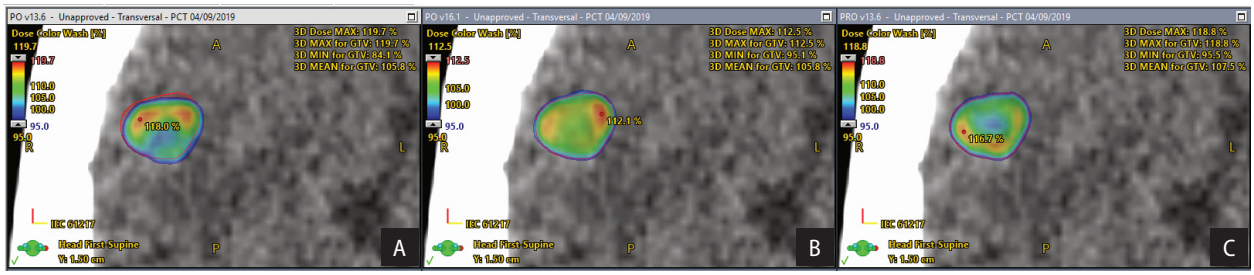


**Figure 4.** Dose colour wash in transversal view at Iso-centre for: **A.** Photon Optimizer (PO) v13.6; **B.** PO v16.1; **C.** Progressive Resolution Optimizer (PRO) v13.6

volving smaller target volumes. This kind of skew is absent in both PO v16.1 and PRO v13.6 with mean CMD values of 0.01cm and 0.02cm which are much lower compared to the image resolution. The dose distribution skew is pictorially represented with profiles in Figure 3e and with dose colour wash in Figure 4 for the optimizers studied. The skew of the dose distribution is not addressed in any of the previous publications comparing PO and PRO.

Similar Brain-GTV 12Gy volume between PO v16.1 and PO v13.6 as indicated by a higher p-value (0.67) in spite of significant improvements in coverage and conformity with PO v16.1 may be attributed to the skewed dose distribution with PO v13.6 resulting in more prescription dose spillage outside the PTV as shown in Figure 4. The statistically significant reduction of Brain-GTV 12Gy volume with PRO v13.6 compared to PO v16.1 despite the higher dose gradient achieved with PO v16.1 may be due to the significant improvement in the dose coverage with PO v16.1 as indicated by the C% and $D_{near\text{-}Min}$ values.

The MU which is an indicator of plan complexity is significantly less with PO v16.1 compared to PRO v13.6 agreeing with the results published earlier (Liu et al and Vikas et al.).

The improvement in dosimetric parameters, in particular CI, GI, C%, CMD with PO v16.1, may be attributed to its improved structure modelling as it accounts for the structure's contour resolution during the calculation of voxel resolution of matrix which is used by the optimizer for defining structures, DVH calculation and dose sampling. The same factor may be attributed to the dependence of CI improvement with PO v16.1 on PTV size.

The switching over from PRO and earlier version of PO to PO v16.1 with the same planning approach with similar objectives as that of PRO will result in comparable or improved plan quality with PO 16.1. However, if skew compensation planning structures were used in earlier versions of PO, for example PO v13.6 that is no longer required in PO v16.1

## Conclusion

The PO v16.1 generated plans are dosimetrically superior to PO v13.6 and PRO v13.6 in terms of target dose coverage and dose gradient with lesser beam modulation and plan complexity without increasing the normal brain dose to clinically considerable values for single lesion brain SRS. Progressing from PRO v13.6 to PO v16.1 does not require modification of the planning approach, whereas progression from PO v13.6 requires consideration regarding the skewed dose distribution observed with PO 13.6.

### Conflicts of interest

The authors declare that they have no conflict of interest.

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None declared.

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