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Improvement in plan quality after Implementation of clinical goals in a large network of cancer centers

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ABSTRACT

Clinical Goals (CG) is a tool available in the Varian Eclipse planning system to objectively and visually evaluate the quality of treatment plans based upon user-defined dose-volume parameters. We defined a set of CG for Stereotactic Radiosurgery (SRS) and Intensity-Modulated Radiotherapy (IMRT) based on published data and guidelines and implemented this in a network of cancer centers in India (American Institute of Oncology). A dosimetric study was performed to compare brain SRS and breast IMRT plan quality before and after CG implementation.The CG defined for SRS plans were target $V_{100\%} \geq 98\%$, dose gradient measure (GM) ≤ 0.5 cm, conformity index (CI) 1.0 to 1.2. For breast IMRT plans, CG defined target $V_{100\%} \geq 97\%$, $V_{95\%} \geq 95\%$, $V_{107\%} \leq 2\%$, $V_{105\%} \leq 10\%$, and $D_{max} \leq 2.4$ Gy. Dose limits to organs-at-risk (OAR) were summarize in supplemental materials. Twenty brain SRS and 10 breast IMRT treatment plans that were previously delivered on patients were selected and re-planned using CG. The pre and postoptimized plan parameters were compared using student t-tests.For brain SRS plans, the V_{100}, GM, and CI for the pre- and post-Clinical-Goals plans were 93.22% ± 7.2% vs 97.96% ± 0.29% ($p = 0.009$), 0.63 ± 0.16 vs 0.42 ± 0.05 ($p < 0.001$) and 1.07 ± 0.18 vs 1.06 ± 0.06 ($p = 0.79$), respectively. There were no differences in max dose to OARs. In breast IMRT plans, the target $V_{107\%}$ for pre and postimplemented plans were 16.50% ± 10.98% vs 0.32% ± 0.32%, respectively ($p = 0.001$). The average target $V_{105\%}$ were 44.00% ± 15.72% and 8.69% ± 4.53%, respectively ($p < 0.001$). No differences were found in the average target $V_{100\%}$ ($p = 0.128$) and $V_{95\%}$ ($p = 0.205$). The average target D_{max} were 112.28% ± 1.59% and 109.14% ± 0.73%, respectively ($p < 0.001$). There were only minor differences in doses to OARs.The implementation of CG in Varian Eclipse significantly improved SRS and IMRT plan quality with enhanced coverage, dose GM, and CI without increased dose to OARs.

Introduction

Over the past few decades, rapid advancements in radiotherapy delivery capabilities came at the cost of increasing complexity in treatment planning.[1,2] The increasing need for radiation precision, homogeneity, conformity, and more individual organs-at-risk (OARs) have made it challenging to efficiently generate consistent, high quality radiotherapy treatment plans.[3,4] While auto planning software can certainly minimize human subjectivity and time consumption in this planning process, plan quality assurance (QA) is also an important step to ensure the optimization of individual plans to maximize clinical outcomes.[2,5,6]

Treatment plan selection and evaluation can be a highly subjective process. Historically, a popular approach is a physician-based quantitative metrics which are used to assign a score to a dosimetric plan to ensure its adherence based on particular physical criteria.[7] Overall the used indices, though somewhat useful, do not account for the overall dosimetric information provided by dose-

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volume histograms (DVH). Therefore, most treatment centers in the United States and around the world still rely heavily on DVH for evaluation of plan quality.[8] However, due to the similarity of competing tentative plans to the naked eye, considerable skills are required to elicit subtle differences from a mere inspection of the DVHs and isodose curves.[8] Furthermore, DHVs do not provide a clear measure of critical parameters such as target coverage, dose gradient measure (GM), conformity index, and dose to OARs. Therefore, a better tool is needed to for treatment plan evaluation that provides objectivity, flexibility, and ease of use.

Clinical Goals (CG) is a tool introduced to Varian Eclipse™ planning system Version 16.0 in 2020 that objectively and visually evaluate the quality of treatment plans based upon user-defined dose-volume parameters. We implemented CG for common disease sites based on published data and guidelines in our cancer network. For this study we used brain SRS and breast IMRT dosimetry to compare plan quality before and after CG implementation.

Materials Methods

Treatment plan selection

For this study, 20 brain SRS plans and 10 breast IMRT plans previously used for clinical treatment on patients in 2021 and 2022 were selected from the American Oncology Institute, which includes a large network of 16 cancer centers in South Asia. All plans (SRS and IMRT), before and after CG implementation, were generated using Varian Eclipse™ planning system Version 16 and Anisotropic Analytic Algorithm.

CG parameters for SRS

Based on published data from QUANTEC and AAPM-RSS, the Varian Eclipse™ Version 16.1 CG tool defined for brain SRS included the following plan quality measures: target $V_{100\%} \geq 98\%$, dose gradient measure (GM) $\leq$ 0.5-cm, conformity index (CI) 1.0 to 1.2, mean dose to brain $<$ 8 Gy, and maximal dose (for 3 types of fractionations) to OARs such as the optic chiasm, lens, optic nerve, brainstem, and cochlea is listed in Appendix A. Target volume was characterized as gross target volume with a 2-mm PTV margin.

Treatment plans were generated using a VMAT technique for a TrueBeam™ STx equipped with a high definition multileaf collimators. A minimum of 5 arcs (3 non-coplanar, 90, 70, 50 degrees) and maximum of 6 arcs (3 non-coplanar) were used. For full arcs, gantry angles were 181 to 170 degrees. For non-coplanar arcs, half arcs, or partial arcs, gantry angles were 181 to 0 or 181 to 330 degrees. The typical collimation angles were 10, 15, 25, 350, 325, 95, 85, and 125 degrees, depending on the PTV shape and surrounding OARs. To maintain the CI and GM to the PTV, 3 concentric ring structures were used, each ring has a 5-mm thickness with 1-mm gap between each ring. Optimization priority for PTV was 150, first ring was 140, with second and third ring priorities greater than the PTV priority. For example, if PTV priority is 150, the priority for second and third ring are 160 and 175, respectively. The prescription isodose line takes from 70% to 80% for all plans. Dose and fractionations varied for each plan due to the initial physician's discretion. Twenty brain SRS treatment plans previously delivered in clinical practice were re-planned with the use of CG, with all plans done by the same dosimetrist. Along with dose to OARs, target V_{100}, dose GM, and CI were calculated for all plans, including retrospectively for the pre-CG plans since they were not evaluated using these parameters. The parameter values of pre- and post-implementation were then compared using student t-tests and χ^2 tests.

CG parameters for IMRT

Based on NRG and Patel et al., the Varian Eclipse™ Version 16.1 CG tool defined for breast IMRT included the following plan quality measures: Target $V_{100\%} \geq 97\%$, $V_{95\%} \geq 95\%$, $V_{107\%} \leq 2\%$, $V_{105\%} \leq 10\%$, $D_{max} \leq 107\%$; opposite breast $D_{max} \leq 2.4$ Gy; heart $V_{16\%} \leq 5\%$, and $D_{mean} \leq 1.6$ Gy; ipsilateral lung $V_{16\%} \leq 15\%$, $V_{8\%} \leq 35\%$, and $V_{4\%} \leq 50\%$; contralateral lung $V_{4\%} \leq 10\%$.

Treatment plans were generated with 9 fields of fixed IMRT technique with multiple energies (6X and 15X). Typical gantry angles were 298, 315, 330, 135, and 155 degrees for breast PTV; 335, 355, 20, and 175 degrees for supraclavicular nodes. Out of 9 fields, 5 beams were used for breast or chest wall and 4 beams were used for supraclavicular fossa PTV. Higher energies (15X) were used, where the depth is more than 10-cm to achieve PTV conformity, especially to meet the goals of $V_{105\%}$ and $V_{107\%}$. The prescription dose was 42.56Gy in 16 fractions. Two rings were used, Ring 1 for maintaining conformity for PTV and Ring 2 minimizing dose spillage outside the PTV. Similar to brain SRS plans, ten breast IMRT plans previously used in clinical practice were re-planned with the use of CG, and again, with all plans done by the same dosimetrist. The above parameter values were calculated for all plans before and after CG implementation and compared using student t-tests.

Table 1
Average brain SRS plan parameters before and after clinical goals implementation

Parameter	Before clinical goals	After clinical goals	*p*-value
Target $V_{100\%}$ (%)	93.22 ± 7.20	97.96 ± 0.29	0.009
Dose GM (cm)	0.63 ± 0.16	0.42 ± 0.05	<0.001
Conformity index	1.07 ± 0.18	1.06 ± 0.06	0.794
Brainstem D_{max} (Gy)	5.85 ± 7.54	5.32 ± 7.47	0.270
Left optic nerve D_{max} (Gy)	0.55 ± 0.93	0.64 ± 0.70	0.549
Right optic nerve D_{max} (Gy)	1.06 ± 1.84	1.24 ± 2.21	0.312
Optic chiasm D_{max} (Gy)	1.50 ± 2.73	1.89 ± 2.83	0.044
Brain D_{mean} (Gy)	0.91 ± 0.69	0.91 ± 0.61	1.000
Left cochlea D_{max} (Gy)	1.46 ± 3.87	1.17 ± 2.57	0.359
Right cochlea D_{max} (Gy)	3.26 ± 6.21	3.27 ± 6.37	0.681
Left lens D_{max} (Gy)	0.25 ± 0.52	0.30 ± 0.31	0.667
Right lens D_{max} (Gy)	0.35 ± 0.50	0.29 ± 0.38	0.623

Table 2
Average breast IMRT plan parameters before and after clinical goals implementation

Parameter		Before clinical goals	After clinical goals	*p*-value
PTV	$V_{100\%}$ (%)	93.90 ± 2.08	95.00 ± 0.00	0.128
	$V_{95\%}$ (%)	98.70 ± 1.08	99.25 ± 0.37	0.205
	$V_{107\%}$ (%)	16.50 ± 10.98	0.32 ± 0.32	0.001
	$V_{105\%}$ (%)	44.00 ± 15.72	8.69 ± 4.53	<0.001
	D_{max} (%)	112.38 ± 1.59	109.14 ± 0.73	<0.001
Opposite breast	D_{max} (Gy)	19.59 ± 9.85	16.76 ± 11.90	0.552
Heart	$V_{16\%}$ (%)	8.70 ± 11.87	4.28 ± 2.68	0.302
	D_{mean} (Gy)	4.22 ± 1.01	2.92 ± 0.92	0.002
Ipsilateral Lung	$V_{16\%}$ (%)	15.17 ± 2.55	16.29 ± 3.86	0.239
	$V_{8\%}$ (%)	35.64 ± 8.18	27.26 ± 5.85	0.025
	$V_{4\%}$ (%)	72.23 ± 14.52	45.37 ± 11.70	<0.001
Contralateral lung	$V_{4\%}$ (%)	22.06 ± 17.63	0.65 ± 1.56	0.005

Results

The impact of the CG tool on SRS treatment plan quality

The quality of brain SRS treatment plans improved significantly with the use of CG for certain parameters (Table 1, full data presented in Appendix A). The average target $V_{100\%}$ (≥98%) in pre and postimplemented plans were 93.22% ± 7.2% and 97.96% ± 0.29%, respectively ($p = 0.009$). For dose GM (≤0.5), the average were 0.63 ± 0.16 cm and 0.42 ± 0.05 cm for pre and post plans, respectively ($p < 0.001$). No differences were found between the pre and post plans for average CI, which were 1.07 ± 0.18 and 1.06 ± 0.06, respectively ($p = 0.79$).

Only 14 of 20 preimplemented plans met a V_{100} of ≥98%, 2 of 20 met a GM ≤0.5 cm, and 12 of 20 met a CI between 1.0 and 1.2, compared to 100% met in all postimplemented plans ($p < 0.001$, $p < 0.001$, $p = 0.005$, respectively) (Table 1). Dose to OARs did not change significantly with the use of CG except for 1 case of left cochlea.

In Plan 2 and Plan 4 (Appendix A), significant differences in $V_{100\%}$ between the pre-CG and post-CG plans were observed (Plan 2: 85.00% vs 98.00%; Plan 4: 69.60% vs 98.00%).

The impact of the CG tool on IMRT treatment plan quality

Similar to brain SRS plans, certain breast IMRT treatment plan parameters also improved after CG use (Table 2, full data presented in Appendix B). The average target $V_{107\%}$ (≤2.0% as specified by guidelines) were 16.50% ± 10.98% and 0.32% ± 0.32% for pre and post implemented plans, respectively ($p = 0.001$). The average target $V_{105\%}$ (≤10.0%) were 44.00% ± 15.72% and 8.69% ± 4.53% for the pre and post plans, respectively ($p < 0.001$). No differences were found between pre and post plans for average target $V_{100\%}$ (≥97.0%, $p = 0.128$) and $V_{95\%}$ (≥95.0%, $p = 0.205$). Finally, the average target D_{max} (≤107.0%) for the pre and post plans were 112.28% ± 1.59% and 109.14% ± 0.73%, respectively ($p < 0.001$).

For OARs, there were no differences between pre- and post-implemented plans for the average opposite breast D_{max} (≤2.4 Gy, $p = 0.552$) and average heart $V_{16\%}$ (≤5.0%, $p = 0.302$), but the average heart D_{mean} (≤1.6%) for the pre and post plans were 4.22 ± 1.01 Gy and 2.92 ± 0.92 Gy, respectively ($p = 0.002$).

For the ipsilateral lung, which is also an OAR, the average $V_{8\%}$ (≤35.0%) were 35.64% ± 8.18% and 27.26% ± 5.85% for pre and postimplemented plans, respectively ($p = 0.025$). The average $V_{4\%}$ (≤50.0%) was 72.23% ± 14.52% and 45.37% ± 11.70% for pre and post plans, respectively ($p < 0.005$). There were no differences between the pre and post plans for average $V_{16\%}$ (≤15.0%, $p = 0.239$). For the contralateral

Overview

Clinical goals: All Plans ☐ Evaluate Goals for All Plans

Plan			Σ - Plan Sum
Total Dose			N/A
Clinical Goal Summary			2 / 1 / 7
PTV60	P1	V 60.00 Gy ≥ 97.0 %	82.80 %
	P1	V 95.0 % ≥ 95.0 %	N/A
	P2	D 10.0 % < 63.00 Gy	62.20 Gy
	P2	Dmax ≤ 105.0 %	N/A
Brain Stem	P1	Dmax ≤ 55.00 Gy	57.28 Gy
Cochlea_L	P3	V 35.00 Gy ≤ 50.0 %	0.00 %
Cochlea_R	P3	V 35.00 Gy ≤ 50.0 %	100.00 %
Lt Lens	P4	Dmax ≤ 7.00 Gy	6.26 Gy
Lt Optic Nerve	P1	Dmax ≤ 55.00 Gy	29.50 Gy
Optic Chiasm	P1	Dmax ≤ 55.00 Gy	51.90 Gy
Rt Lens	P4	Dmax ≤ 7.00 Gy	6.01 Gy
Rt Optic Nerve	P1	Dmax ≤ 55.00 Gy	52.40 Gy

Fig. 1. An example of the Varian Eclipse™ Version 16.1 Clinical Goals tool.

lung, the average $V_{4\%}$ (≤10.0%) for the pre and post plans were 22.06% ± 17.63% and 0.65% ± 1.56%, respectively ($p = 0.005$).

In Appendix B, there were significant differences observed in $V_{105\%}$ (44.00 ± 15.72 vs 8.69 ± 4.53, $p < 0.001$) and $V_{107\%}$ (16.50 ± 10.98 vs 0.32 ± 0.32, $p = 0.001$) between the pre-CG and post-CG plans.

Discussion

Currently, many radiotherapy treatment centers in the United States and other countries do not have standardized measures for plan quality evaluation. The plans in this study were previously used clinically before CG implementation, allowing for the assessment of CG's real-world applications. The use of Varian Eclipse™ Version 16.1 CG tool offers a scorecard-based indication for optimization, leading to enhanced overall plan quality based on guideline-defined limitations without any inherent changes to the software planning process. However, CG is not an independent optimization tool and therefore cannot automatically adjust the constraints of the failed structures during optimization.

In brain SRS plans, the target conformity and OAR sparing is similar before and after the implementation of CG, but target coverage and dose GM improved significantly. The CG tool provides direct visualization of such parameters, many of which cannot be evaluated directly on DVHs without further calculations. Therefore, this tool can easily identify the deficiencies of a plan and help achieve the specified target coverage, gradient, and conformity without compromising OAR sparing. For breast IMRT plans, target homogeneity, mean heart dose, as well as lung doses significantly improved with CG implementation. Given the variation in expertise of physicians and dosimetrists in the treatment centers around the world, CG can provide a boost in plan quality through assessment of not only DVHs, but also finer indices that DVHs do not account for.

The profound differences found in SRS Plan 2 and 4 (Appendix A) may be due an oversight by the physician when reviewing the plan based on DVH parameters, leading to more focus on OAR dose constraints. However, this further exemplifies that CG can identify deficiencies in a plan that can sometimes be overlooked by the treating physician. Before the use of CG, dosimetrists generally were not rigid on dose homogeneity, thus leading to less optimized plans. The implementation of CG allows for appropriate optimization of parameters such as homogeneity, explaining the large discrepancy in PTV $V_{100\%}$, $V_{105\%}$, and $V_{107\%}$ in IMRT plans (Appendix B).

There are several advantages of using CG for plan quality evaluation over manual reliance on DVHs and isodose curves, which are highly subjective. This tool uses color schemes to determine whether specified plan goals were met (green = meets guidelines, yellow = variation acceptable, red = did not meet guidelines) (Fig. 1). In addition, the customizability of CG allows for guideline adjustments based on institutional experience and evolving data during the treatment planning and evaluation process.

Although this study did not provide outcome analysis in which the clinical significance of CG implementation is evaluated, many studies have shown the impact of deviated target delineation and failure of rigorous quality assurance (QA) can result in inferior clinical outcomes.[9-11] For example, Chen et al. reported that deviation from contouring guidelines was associated with suboptimal local control 1 year post spine stereotactic body radiotherapy (SBRT) (63.0% vs 85.5%, $p < 0.001$).[10] Improvement in dose gradient with SRS can help reduce dose to uninvolved brain which can reduce risk of necrosis. Similarly dose homogeneity improvement in breast planning leads to better cosmetic outcome. In conclusion, the results of this study showed that CG's user defined acceptance criteria set as clinical goals for plan evaluation can improve overall plan quality. Institutions around the world could implement the use of the Varian Eclipse™ Version 16.1 CG for all disease sites for its objectivity, customizability, and ease of use in plan quality evaluation.

Declaration of Competing Interest

Mr Hefei Liu had recent employment with Varian Medical Systems in the last 12 months. Dr Sushil Beriwal has a leadership role as the Vice President of Medical Affairs at Varian Medical Systems, reports grant as an Elsevier consultant, and reports participation in advisory board at Xoft DSMB. Dr Deepak Khuntia has a leadership role as the Senior Vice President and Chief Medical Officer at Varian Medical Systems. Mr Praveen Nuksani, Dr Malolan Rajagopalan, Dr Mangesh Patil, Dr Krishna Komanduri, and Mr Brent Murphy have nothing to disclose.

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Data sharing statement

Research data is stored in Varian repository and will be shared upon request to the corresponding author.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.meddos.2022.10.003.

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