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Assessment of monitor unit limiting strategy using volumetric modulated arc therapy for cancer of hypopharynx

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A B S T R A C T

Purpose: To quantify relative merit of MU deprived plans against freely optimized plans in terms of plan quality and report changes induced by progressive resolution optimizer algorithm (PRO3) to the dynamic parameters of RapidArc.
Materials and methods: Ten cases of carcinoma hypopharynx were retrospectively planned in three phases without using MU tool. Replicas of these baseline plans were reoptimized using "Intermediate dose" feature and "MU tool" to reduce MUs by 20%, 35%, and 50%. Overall quality indices for target and OAR, integral dose, dose-volume spread were assessed. All plans were appraised for changes induced in RapidArc dynamic parameters and pre-treatment quality assurance (QA).
Results: With increasing MU reduction strength (MURS), MU/Gy values reduced, for all phases with an overall range of 8.6–34.7%; mean dose rate decreased among plans of each phase, phase3 plans recorded greater reductions. MURS20% showed good trade-off between MUs and plan quality. Dose-volume spread below 5 Gy was higher for baseline plans while lower between 20 and 35 Gy. Integral dose was lower for MURS0%, not exceeding 1.0%, compared against restrained plans. Mean leaf aperture and control point areas increased systematically, correlated negatively with increasing MURS. Absolute delta dose rate variations were least for MURS0%. MU deprived plans exhibited GAI (>93%), better than MURS0% plans.
Conclusion: Baseline plans are superior to MU restrained plans. However, MURS20% offers equivalent and acceptable plan quality with mileage of MUs, improved GAI for complex cases. MU tool may be adopted to tailor treatment plans using PRO3.

1. Introduction

The advent of intensity modulated radiotherapy (IMRT) using multileaf collimators (MLCs) brought designing and escalation of conformal doses into clinical practice [1,2]. Better sparing of critical structures was realized due to rapid dose fall-off outside target boundaries. On the other hand, discretization of the delivery pattern by MLCs carried with it the burden of monitor units (MUs) which is considered to cause secondary malignancies though the calculated risk is small [3–5] and data is yet to mature to establish the actual results. To generate deliverable MLC segments, planning systems adopted one-step optimization strategies such as direct aperture optimization (DAO) and direct machine parameter optimization (DMPO) which consider machine constraints during optimization to reduce the complexity of treatment delivery to a great extent as compared to the conventional formulation of two-step optimization strategy. Several studies have established the superiority of one-step optimization strategies over two-step strategies in terms of MU efficiency, treatment time and plan quality [6,7].

Otto [8] proposed an aperture-based algorithm, to exploit modulation of dose rate (DR), gantry speed (GS) in addition to MLC shapes, which provide additional degrees of freedom for optimization. Several studies evaluated different techniques, comparing planning results, for various treatment sites [9–11]. Otto's work was later adopted with some differences and implemented commercially as RapidArc (Varian Medical Systems, Palo Alto, CA, USA). RapidArc form of volumetric modulated arc therapy (VMAT) utilizes progressive resolution optimizer (PRO) algorithm. This optimization engine generates combinations of DR, GS and MLC shapes to attain MU per degree, respecting machine constraints. Recently, VMAT has been widely adopted in clinical practice as it provides equal or better planning results conserving treatment time and MUs in comparison to other rotational and static IMRT

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delivery techniques [12,13]. Several studies compared different delivery techniques, but few investigations evaluated optimization strategies of RapidArc exclusively [14,15]. The two generations (versions) of PRO algorithm available are well described with graphical schematics [16]. Specific investigations on the first generation optimizer (version 8.6), reported [15,17] influence of MU optimization parameters on plan quality for prostate cases showing that optimizer reduced MUs considerably, retaining comparable plan quality from its baseline optimization. Vanetti et al. [16] in their study concluded that the second generation optimizer algorithm called as PRO3 (version 10.0) converges faster than its predecessor PRO2 (version 8.9). Furthermore, it was established that the efficiency of MUs and plan quality depend on optimization algorithm and other influencing parameters [16,18–21].

Eclipse treatment planning system (TPS) uses PRO which includes MU optimization tool as a feature, to control MUs required for the delivery of prescribed dose. This tool is comprised of three parameters, namely Minimum MU (Min MU), Maximum MU (Max MU), and Strength (S). Min MU and Max MU parameters specify lower and upper bounds on MUs to be achieved for the given treatment plan. The former increases MUs, which tends to add modulation in the optimization process and the later acts the other way. Strength parameter controls the convergence of total MUs to the bounds set by the above parameters. Although the functions of these parameters are well described [14,15], users may not be familiar as to how these parameters influence PRO to achieve planning goals. In this context, it is imperative to assess the task of limiting MUs by RapidArc optimization engine. A systematic methodology is set up to analyze this facet of the optimizer and its influence on plan quality. Three different case scenarios encountered in a typical head and neck treatment are chosen to evaluate the optimizer performance in relation to a defined set of parameters. This work attempts to investigate the factors responsible for the resultant MUs and the obvious changes manifested by PRO3 algorithm in the treatment plan.

2. Materials and methods

Ten consecutive head and neck cases of carcinoma Hypopharynx treated over a period of six months were selected for RapidArc planning. A total dose of 66 Gy in 33 fractions was planned with shrinking target volumes receiving 46 Gy, 14 Gy, and 6 Gy in three consecutive phases. Planning target volumes (PTV) were complex and large in the first phase whilst regular and small in the final phase and the intermediate phase carried moderate features (Fig. 1). The relevant organs at risk (OAR) in the region of interest (ROI) are spinal cord, brain stem, parotid glands and oral cavity. OAR doses were planned conservatively to reduce the constrained dose maximum of 45 Gy to the spinal cord, 54 Gy to the brainstem, mean dose of 20 Gy to one or 25 Gy to both parotid glands and 40 Gy to the oral cavity. The total dose was delivered using two arcs per plan with a symmetric gantry span of 320^{o} for first phase and 240^{o} for second and third phases. Gantry arc was spread between 200° and 160°, for phase1 and between 240° and 120° for phase2 and phase3 plans. For the clockwise arc, collimator was set to 10° and a complementary angle of 80° was used for the counterclockwise arc. Treatment fields were defined by HD120 MLC having projected leaf width of 2.5 mm at isocenter spanning the central 8 cm and 5 mm width leaves making up the peripheral 14 cm. Two arcs were used for planning head and neck cases to achieve better plan quality. Although one arc would suffice for final phase, two arcs were used to maintain uniformity of comparison with remaining phases of treatment. All the treatment plans were optimized for 6 MV photon beam with a maximum allowed dose rate of 600 MU/min. Eclipse treatment planning system with PRO version 10.0.28 (PRO3) was used to optimize dynamic parameters of RapidArc. Volume dose was calculated by means of anisotropic analytical algorithm (AAA) version 10.0.28 with a calculation grid resolution of 2.5 mm and heterogeneity correction applied.

A baseline plan for each phase was generated without using MU objective tool and the optimization process was driven by incrementing priority values for OARs from 60% to 70% of that used for target structures. Three replicas for each phase were created by copy-pasting the baseline plans and were re-optimized by PRO3, retaining the calculated dose distribution of baseline plans using a new feature called the intermediate dose option. This strategy helps to understand the changes made to baseline plans without starting a new loop, which might converge to a completely different solution. As our intention was to reduce MUs, only the Max MU parameter was altered while the strength parameter was set to a constant value equal to 100 and Min MU parameter was left blank. Replicated plans were constrained at the beginning of re-optimization, to obtain 80%, 65% and 50% of MUs supplied by the baseline plan of the respective phases. Thus, a set of twelve plans per patient were generated, multiplying three phases with three expected MU reduction strengths, 20%, 35%, and 50%, in addition to the three baseline plans. Plans with these MU reduction strengths were termed as MURS20%, MURS35% and MURS50% along with MURS0% (baseline plan) for the three phases and used in this context wherever required. All other parameters that may affect the optimization process were kept same to nullify their influence on the MU constrained plans. Moreover, all the plans were generated by a single planner to rule out planner bias. re-optimization of MU constrained plans begins at the final resolution level and PRO3 tries to reduce the MUs. A subtle change observed in the dose volume histogram (DVH) calculated by multi-resolution dose calculation (MRDC) algorithm and the objective

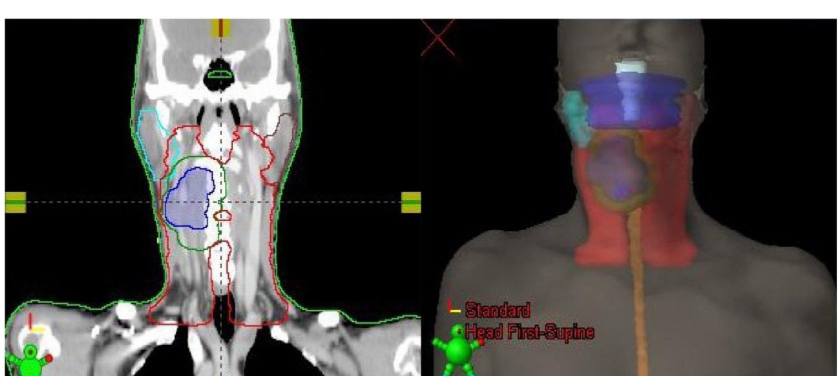

Fig. 1. Coronal and 3D views of target volumes and OAR of a representative case.

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