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Investigation of plan quality between RapidArc and IMRT for gastric cancer based on a novel beam angle and multicriteria optimization technique

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A novel beam angle and multicriteria optimization (BAMCO) for intensity modulated radiotherapy (IMRT) was tested in ten gastric cancer patients. BAMCO IMRT has similar target coverage and organs at risk sparing to RapidArc. A reasonable delivery time (189.3 ± 26.0 s) was found for the BAMCO IMRT technique although longer than VMAT's (65.0 ± 9.7 s).

The quality of intensity modulated radiation therapy (IMRT) depends on the choice of beam orientations, numbers, optimization algorithms, and operator experience. Generally, beam orientations are selected either from a preset template or from several trial-and-error procedures by the planner. Beam orientations taken directly from a template may be suboptimal and trial-and-error procedures are long and time-consuming. Some investigators have attempted to provide optimization for gantry angle and have shown the reduction of monitor units (MUs) and segments without sacrificing target coverage or organs at risk sparing [1–4].

The planner makes certain prescriptions for the desired dose to the target and organs at risk (OARs) with weight factors after setting the beam orientations. Several trial-and-error optimization processes are usually required in current treatment planning systems and conventional approaches to achieve a clinically acceptable plan. But even if a final plan is acceptable for treatment it may be still possible to find a better plan if using more parameter settings [5]. The potential of IMRT is not exploited to its full extent because of these limitations in the current inverse planning process. Multicriteria optimization (MCO) provides the solution for this problem [6–9]. The MCO offers a large number of promising choices and the planner or physician can efficiently explore tradeoffs between different treatment planning goals and decide the clinically optimal compromise. It results in shorter planning times and more satisfactory results [10,11].

The RapidArc has the characteristics of both good plan quality and high delivery efficiency [12–14]. However, advanced machine hardware (Linac) and additional quality assurance work are required for implementing RapidArc [15]. It will be useful to find a new optimization method for fulfilling the requirements of maintaining plan quality and having high delivery efficiency. The purpose of this study is to combine the beam angle and multicriteria optimization (BAMCO) for achieving an IMRT plan with plan quality and delivery efficiency similar to RapidArc and to perform a preclinical investigation of this technique for gastric cancer radiotherapy.

Materials and methods

Patient selection and contouring

Ten gastric cancer patients previously treated in Trilogy machine (Varian Medical System, Palo Alto, CA) with RapidArc technique in 2012 were retrospectively reviewed and enrolled in this study. All patients had T3–4 and/or N+, staging II-IV gastric cancer and were immobilized using an arm support (CIVCO Medical solution, Iowa) and a homemade feet support. The clinical target volume (CTV) included the gastric bed, anastomosis with 2-cm proximal/distal margins, and regional LN areas. The CTVs were delineated according to preoperative and pathologic descriptions. The planning target volume (PTV) consisted of CTV plus a 7 mm margin in all directions. Normal tissues included the kid-

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neys, liver, and spinal cord. The RapidArc was created in the Eclipse treatment planning system (v8.6, Varian Medical System, Palo Alto, USA) using a one-arc plan with the gantry rotated clockwise from 270° to 179°. Radiotherapy delivered 45 Gy to the PTV in 25 fractions. All RapidArc plans met the following requirements: (1) at least 95% of PTV received 45 Gy; (2) the volume of kidney receiving 15 Gy (V15) was less than 50%; and (3) the volume of liver receiving 30 Gy (V30) was less than 30%.

Beam angle and multicriteria optimization (BAMCO) workflow

All the planning data including the CT data sets, the RT structures, and the RT plans were exported to the RayStation treatment planning system (Version 3.0, RaySearch Laboratories AB, Stockholm, Sweden) for RapidArc dose recalculation and BAMCO IMRT designing. The same Trilogy machine was commissioned in the RayStation and the recalculated dose distributions between the Eclipse and RayStation were verified within 1.5%.

The overall workflow of BAMCO is as follows:

(1) Import all the CT images and RT structures.
(2) Create a new plan for each patient with the same isocenter to the original RapidArc plan.
(3) Manually add 6 beams based on a prior knowledge in our department. We use 290°, 330°, 0°, 45°, 90° and 170° as the original beams.
(4) Add objectives for beam angle optimization.
(5) Start the BA optimization.
(6) Use the beam angles from BA optimization as the final beam orientations.
(7) Add objectives and constraints for the MCO.
(8) Start MCO process.
(9) Navigate the plan database and select the optimal plan (BAMCO plan).
(10) Obtain the deliverable BAMCO plan.

The whole process was performed on the RayStation and the final BAMCO plan was compared to the recalculated RapidArc plan.

Dose comparison

For consistency of comparison, all ten plans were normalized to deliver 45 Gy to 95% of the PTV. The dose–volume histograms of the BAMCO IMRT and RapidArc plans were compared for all the patients. For the target, the dose conformity and homogeneity were compared. For organs at risk, the maximum dose to spinal cord, the mean and V*x* (the percent of volume that at least received × Gy) to the liver ($x = 30$) and kidneys ($x = 20$ and 15) were compared. Dose conformity and homogeneity were represented by the conformity index (CI) [16] and homogeneity index (HI) [17], respectively. The closer the CI is to 1, the better the dose conformity. Furthermore, the integral dose to the PTV and the normal tissue (NT) were obtained. The normal tissue (NT) was defined as all the external contour except the PTV. The integral dose was reported as the sum of all dose voxels times their mass [18]. In this study, the densities of PTV and NT were both considered as 1 for simplification. Therefore, the integral dose was equal to the mean dose multiplied by the volume.

Dry runs were performed on all BAMCO IMRT and RapidArc plans and the treatment delivery times were recorded.

Statistics

A paired two-tailed Student *t*-test was used for data analysis. The threshold for statistical significance was $p < 0.05$. All data were analyzed on the SPSS, version 20.

Results

The mean volume of PTV was 1008 cc (range 583–1528 cc). The typical dose distributions and dose volume histograms (DVHs) from one patient for BAMCO IMRT and RapidArc are illustrated in Fig. 1. Both techniques had similar target coverage. The mean values and standard deviations of the study parameters for the two techniques are tabulated in Table 1.

Target coverage

All plans met the prescription requirement. The CI for BAMCO and RapidArc were 0.94 ± 0.01 and 0.95 ± 0.01, respectively. The HI was 1.16 ± 0.01 for BAMCO IMRT and 1.14 ± 0.03 for RapidArc. There were no significant differences on CI and HI between the two techniques (both $p > 0.05$).

Organs at risks

All the plans meet the required dose limitations. Although DVHs of the example case in Fig. 1 show obvious dose deviation in spinal cord between BAMCO IMRT and RapidArc, the mean maximum spinal cord dose for both BAMCO IMRT and RapidArc was 33.6 Gy ($p = 0.32$). The BAMCO IMRT produced a similar mean liver dose (18.9 Gy vs. 19.3 Gy, $p = 0.34$) and mean V30 (21.3 vs. 22.1, $p = 0.62$) to RapidArc.

For the right kidney, BAMCO IMRT had significantly lower dose to RapidArc in mean dose (11.1 Gy vs. 13.6 Gy, $p = 0.04$) and V15 (23.2 vs. 38.3, $p = 0.01$). The mean dose and mean V15 to the left kidney were 12.5 Gy and 27.4 Gy in the BAMCO IMRT, which were lower than RapidArc with 14.6 Gy ($p = 0.00$) and 38.5 Gy ($p = 0.01$), respectively. There were no significant differences for both kidneys in V20 (both $p > 0.05$).

Integral dose and treatment delivery time

The mean integral dose to PTV (NT) was 48.0 J (133.6 J) in BAMCO and 47.8 J (134.7 J) in RapidArc. Both techniques had similar integral dose to PTV and normal tissue (both $p > 0.05$).

The segments were 14–15 (14 for eight patients and 15 for two patients) for the BAMCO IMRT. The total MU for BAMCO and RapidArc were 342.0 ± 95.0 and 362.0 ± 43.0 ($p = 0.09$), respectively. The corresponding treatment delivery time was 189.3 ± 26.0 s (range 159–230 s) to BAMCO and 65.0 ± 9.7 s (range 55–76 s) to RapidArc ($p = 0.00$). The BAMCO IMRT showed the feasibility of completing the treatment delivery within 4 min with a dose rate of 400 MU/min.

Discussion

In this study, a new BAMCO strategy was created for IMRT planning. Our study shows that the BAMCO IMRT has sufficient target coverage and superior OARs sparing to the RapidArc. To the best of our knowledge, this is the first time to implement this strategy in gastric cancer radiotherapy.

The BAMCO strategy implemented in this study maintains the characteristics of both beam angle and multicriteria optimizations. As shown in our result, the final segments for BAMCO IMRT with 6 beams ranged from 14–15, corresponding to 1–3 segments per beam; and the average MUs were 342. Wieland et al. investigated the conventional IMRT method on gastric cancer with 8 beams [19]. They found the average number of segments amounting to 49 (range, 37–77) and the average number of MUs being 1358 (range, 1018–1814). In comparison, the BAMCO IMRT in our study only has about 1/4 to 1/3 of their MUs and segments. The significant reduction of MUs and segments was directly related to the