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Single-arc volumetric-modulated arc therapy (sVMAT) as adjuvant treatment for gastric cancer: Dosimetric comparisons with three-dimensional conformal radiotherapy (3D-CRT) and intensity-modulated radiotherapy (IMRT)

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A B S T R A C T

To compare the dosimetric differences between the single-arc volumetric-modulated arc therapy (sVMAT), 3-dimensional conformal radiotherapy (3D-CRT), and intensity-modulated radiotherapy (IMRT) techniques in treatment planning for gastric cancer as adjuvant radiotherapy. Twelve patients were retrospectively analyzed. In each patient's case, the parameters were compared based on the dose-volume histogram (DVH) of the sVMAT, 3D-CRT, and IMRT plans, respectively. Three techniques showed similar target dose coverage. The maximum and mean doses of the target were significantly higher in the sVMAT plans than that in 3D-CRT plans and in the 3D-CRT/IMRT plans, respectively, but these differences were clinically acceptable. The IMRT and sVMAT plans successfully achieved better target dose conformity, reduced the $V_{20/30}$, and mean dose of the left kidney, as well as the $V_{20/30}$ of the liver, compared with the 3D-CRT plans. And the sVMAT technique reduced the V_{20} of the liver much significantly. Although the maximum dose of the spinal cord were much higher in the IMRT and sVMAT plans, respectively (mean 36.4 *vs* 39.5 and 40.6 Gy), these data were still under the constraints. Not much difference was found in the analysis of the parameters of the right kidney, intestine, and heart. The IMRT and sVMAT plans achieved similar dose distribution to the target, but superior to the 3D-CRT plans, in adjuvant radiotherapy for gastric cancer. The sVMAT technique improved the dose sparings of the left kidney and liver, compared with the 3D-CRT technique, but showed few dosimetric advantages over the IMRT technique. Studies are warranted to evaluate the clinical benefits of the VMAT treatment for patients with gastric cancer after surgery in the future.

Introduction

Gastric cancer occurs with high incidence rate in West China. Although there are many protocols in managing of this type of disease, surgery remains as the key strategy of the treatment for the locally advanced gastric cancer. After operation, the locoregional relapse rate was nearly 30% to 50%, and almost half of these relapses were the only sites of the failures observed in clinical practice.[1,2] As the results of the Gastric Surgical Adjuvant Trial Intergroup 0116 (INT 0116) were published, chemoradiotherapy was established as the standard adjuvant treatment for locoadvanced gastric cancer after surgery.[3] In this landmark trial, adjuvant chemoradiotherapy improved the 3-year median survival to 36 months compared with 27 months in the surgery-alone group in T3/4 or N-positive patients with high-risk, resected gastric cancer.

INT 0116 radiation therapy approach has involved 2-dimensional treatment planning, mostly with a standard anteroposterior-posteroanterior field arrangement. The consequences were obvious, giving rise to the side-effects that necessitated termination of the therapy in nearly 17% of patients.[3] With the development of conformal radiotherapy, 3-dimensional conformal radiotherapy (3D-CRT) showed a superior dose distribution and normal tissue sparing, and became the routine application in radiotherapy treatment planning. As the

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Table 1
Basic and clinical characteristics of the studied patients ($n = 12$)

Age (y)	
Median	57
Range	43 to 70
Sex	
Male	7
Female	5
Disease stage	
II	2
IIIA	3
IIIB	5
IV (M0)	2
Tumor location	
Upper third	4
Middle third	4
Lower third	4
Extent of node dissection	
D1	2
D2	10

implementation of the intensity-modulated radiotherapy (IMRT), the issue of whether the IMRT technique was better than the 3D-CRT technique as adjuvant treatment for gastric cancer has been discussed, and the conclusions have been considered as controversial.[4–7]

Volumetric-modulated arc therapy (VMAT), a rotational form of IMRT, has been introduced into clinical practice with other treatment methodologies recently, including lung cancers,[8,9] prostate cancer,[10] and anal cancer.[11] Based on a number of studies, it has been pointed out that the VMAT technique might reduce the treatment time without compromising plan quality compared with IMRT in radiotherapy planning for different cancer types. In adjuvant treatment planning for gastric cancer, only one study focused on the dosimetric differences between IMRT and arc radiotherapy (tomotherapy), which indicated that tomotherapy was similar to the IMRT technique.[4]

Until now, no study has been published comparing the 3D-CRT, IMRT, and VMAT techniques in treatment planning for postoperative gastric cancer. In this article, we report our planning analysis for locally advanced gastric cancer after surgery, comparing the dosimetric parameters derived from 3D-CRT, IMRT, and VMAT plans.

Methods and Materials

This study was conducted between June 2011 and January 2012. In total, 12 patients with confirmed locally advanced gastric cancer who had undergone surgery were randomly selected for analysis. These patients were treated following the protocol as we reported previously (radiotherapy with regimen of oxaliplatin, 5-fluorouracil, and leucovorin).[12] The patient characteristics were listed in Table 1. All patients were staged according to the 2010 American Joint Committee on Cancer staging system.[13] Permission to conduct the study was granted by the Research Ethics Board of the University Health Network.

Target delineation and dose prescription

Patients underwent computed tomography (CT)-based simulation in the supine position (Siemens, Somatom Plus[4]) with 3-mm CT slices. A custom immobilization device was used to minimize setup variability. All of the CT images of the patients were transferred to and registered in the treatment planning system (TPS).

Targets and normal tissues definitions in this study were in accordance with the Radiation Therapy Oncology Group 50 and 62 reports.[14,15] The clinical tumor volume typically included the original tumor volume, operative bed (as defined by the operative note, pathologic findings, surgical clips, and discussion with the surgeon), and the draining lymphatics at risk, as was described in the INT 0116 study.[3] For the planning target volume (PTV), the 10-mm margin was added isotropically to the clinical tumor volume. The organs at risk (OARs) included spinal cord, heart, kidneys, liver, heart, and intestine. A single physician was assigned for the entire contouring task to avoid any inconstancy among various physicians.

All generated plans for each patient consisted of 50.4 Gy to be delivered to PTV in 28 fractions. The objective of planning was to ensure 95% volume of PTV receiving the prescribed dose and avoiding the volume receiving 115% of the prescribed dose. All plans were generated for the Elekta Synergy accelerator (Elekta Oncology Systems, Crawley, UK) with 6-MV photons. The dose-volume constraints for the OARs were set as follows: 60% volume of the liver less than 30 Gy and mean liver dose less than 20 Gy; 30% volume of each kidney less than 22 Gy or two-thirds of 1 kidney less than 18 Gy; 95% volume of the intestine less than 45 Gy and maximum dose to the intestine less than 54 Gy; maximum dose to the spinal cord less than 45 Gy; and 30% volume of the heart less than 40 Gy.

Treatment planning and optimizing

(1) *3D-CRT:* These plans were generated using the 4 coplanar beams with 3D conformal dose distribution for the targets in our TPS. Typically, the beams included an anteroposterior-posteroanterior parallel pair and 2 wedged lateral fields. The adjustments of the beam angles, wedge angles, weight coefficient, and other parameters were applied to avoid the OARs, especially the spinal cord and kidneys (Fig. 1A).

(2) *IMRT:* The IMRT plans were optimized with a Direct Machine Parameter Optimization algorithm in our TPS (Pinnacle[3] 9.0 version, Philips Medical System, Madison, WI), as described previously.[16] For each plan, an average of 40 segments were used based on 7 coplanar beams (whose angles were 204°, 256°, 308°, 0°, 52°, 104°, and 156°, respectively) with the angles dependent on the tumor location (Fig. 1B). In the plan generation, the maximum iterations in the plan optimization were 40, and the maximum number of all segments in one plan was restricted to 100. There was no limitation to the minimum monitor units per segment. The OAR dose constraints and the priority weights were set in the plan optimization as the following: for the left kidney, the $V_{30} < 10\%$ (priority weight 30%) and the $V_{20} < 23\%$ (priority weight 30%); for the right kidney, the $V_{30} < 5\%$ (priority weight 30%) and the $V_{20} < 18\%$ (priority weight 30%); for the liver, the $V_{30} < 15\%$ (priority weight 15%) and the $V_{20} < 50\%$ (priority weight 25%); for the intestine, the $V_{40} < 17\%$ (priority weight 30%) and the $V_{50} < 8\%$ (priority weight 10%); for the spinal cord, the maximum dose < 39 Gy (priority weight 15%); and for the heart, the $V_{40} < 15\%$ (priority weight 5%).

(3) *Single-arc VMAT (sVMAT):* The VMAT plans were optimized with the SmartArc planning algorithm in the Pinnacle system. The plan was constrained to use one single 360° arc consisting of 90 control points. The arc was represented by 89 beams with each separated by 4° (Fig. 1C), which started and ended at 180°. The accelerator used an automatic dose rate selection, which ensured that the maximal possible dose rate was chosen for each individual segment of the arc. We applied the same OAR dose constraints and the priority weights as we set in the IMRT planning.

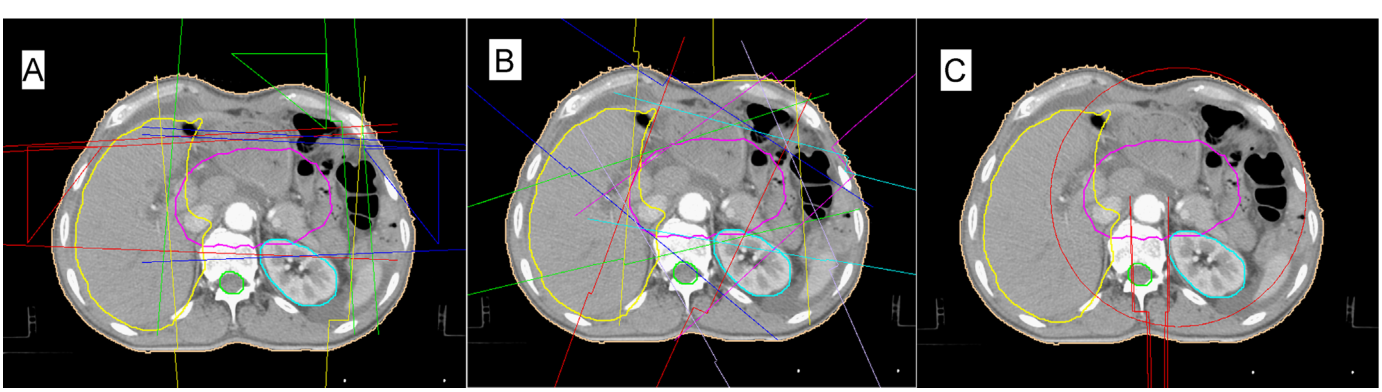

Fig. 1. Representative beam arrangements (A: 3D-CRT plan, B: IMRT plan, and C: VMAT plan). (Color version of figure is available online.)