Comparative study on dosimetry of VMAT and IMRT in assisted radiotherapy after radical resection of rectal cancer

JIANGUO SHI, FUJUN YANG, XIANGBAI JU, YUDONG HUANG and FENGE JIANG

Department of Radiation Oncology, Weihai Municipal Hospital, Weihai, Shandong 264200, P.R. China

Received June 14, 2016; Accepted February 8, 2017

DOI: 10.3892/ol.2017.5842

Abstract. The present study compared the dosimetric differences of volumetric modulated arc therapy (VMAT) and 7-field intensity modulated radiation therapy technology (7F-IMRT) in assisted radiotherapy plan after resection of rectal carcinoma. Ten cases of patients at stages II-III of rectal cancer transabdominal resection with postoperative pelvic radiotherapy underwent 7F-IMRT and VMAT radiotherapy plan design using the CMS Monaco treatment planning system. We compared the dose distribution, the number of organs at risk and the number of machines in the two groups. The 7F-IMRT plans conformal index (CI) was 0.8319±0.0143 and VMAT plans CI was 0.838±0.164. Both plans reached up to the 95% isodose line at a volume of 100% planning target volume (PTV), the 7F- IMRT plans homogeneity index (HI) was 1.0760±0.0179, and the VMAT plans HI was 1.0821±0.0143. CI and HI had no statistical difference. With regard to S40, the V50 dose volume of the small intestine was endangered, and the VMAT plan was better than that of the 7F-IMRT plan, and the difference was statistically significant (P<0.05). The machine hop numbers of the two types of plans were 594.1±36.1 and 793.2 ±56.6 for for VMAT and 7F-IMRT, respectively. The VMAT plan was less than htat of the 7F-IMRT and the difference was statistically significant (P<0.05). Patients to whom VMAT techniques were utilized after resection of rectal cancer obtained an equal or a superior dose distribution compared with the IMRT plan. VMAT had important significance in protecting the small intestine, while significantly reducing treatment time.

Introduction

Rectal cancer is a common malignant tumor occurring in the digestive tract. It is often treated by surgical treatment, but the recurrence rate is high even after operation (1,2). Postoperative radiotherapy may significantly reduce the recurrence rate and improve the quality of life of patients. However, radiation field shape of adjuvant radiotherapy after rectal cancer surgery is complicated, and the associated side effects affect the efficacy of the application in the clinical setting.

In the present study, to improve the target dose distribution of radiotherapy after resection of rectal carcinoma, 7-field intensity modulated radiation therapy technology (7F-IMRT) and volumetric modulated arc therapy (VMAT) were used for radiation therapy, and the radiation dose distributions of rectal cancer after surgery were examined. The differences of volume-dose distribution associations in the treated target area and endangered organs were compared to provide dosimetric basis for optimization of radiotherapy plan after rectal cancer resection.

Materials and methods

General data. Ten cases of patients at stage II-III of rectal cancer transabdominal resection with postoperative pelvic radiotherapy from June 2011 to December 2012 treated at the Weihai Municipal Hospital (Shandong, China) were selected as the study subjects. The patient age range was 42-68 years, KSP up to 70 points. The patients had no radiotherapy contraindications.

CT simulation scanning. The patients were required to empty the bladder 1 h prior to positioning, orally ingested 10 ml diatrizoate meglumine and 1,000 ml of water 3-4 times, holding back urine before CT scan. The patients were placed in a supine position with hot plastic film, and 100 ml iohexol was injected intravenously before CT scanning followed by videography. A Siemens large aperture CT simulation positioning machine (Siemens, Berlin, Germany) was used for the CT scanning, layer thickness was 5 mm, with a total of 60-80 layers, the upper edge was L5, the lower boundary was under sciatic nodules (5 cm). Using the Monaco CMS (3.0 edition; Elekta AB, Stockholm, Sweden) treatment system target areas and normal organs were delineated.

Target area and normal tissue delineation. The same clinicians delineated the target area and organs. CTV was defined as the primary high-risk area and the regional lymph node drainage area. The high-risk area of the primary tumor included the

Correspondence to: Dr Yudong Huang, Department of Radiation Oncology, Weihai Municipal Hospital, 70 Heping Road, Weihai, Shandong 264200, P.R. China
E-mail: huang_yudong1@163.com

Key words: rectal cancer, radiotherapy, dosimetry, intensity modulated radiation therapy, volumetric modulated arc therapy

anastomosis region, the nub rectum, the part of the sigmoid colon, the anterior region of the sacral, the lateral wall of the pelvis, and ischiorectal fossa. The regional lymphatic drainage area included the rectum mesentery area, internal-iliac lymph nodes, or part of the common iliac artery or external blood vessels in and around the lymph nodes and obturator region. CTV upper boundary was under L5 margin, the lower boundaries were under the obturator margin, lateral boundary was the inner edge of the true pelvis, the front boundary was at 1/4 to 1/3 of the back wall, and the back boundary included half of the sacrum (S3 superior border above) and sacral cortices posterior (S3 superior border below). CTV included the lymphatic drainage area of internal and external sacrum above the level of S3, not including the internal and external iliac lymph drainage area below the level of S3. The planning target volume (PTV) comprised the expanded CTV with 0.5 cm to the left and the right, respectively, thereof, and 1.0 cm in the front and the back as well as the head and the foot, respectively. The delineated organs were bladder, small intestine and bilateral femoral heads.

Treatment plan design. The Monaco CMS (3.0 edition, Sweden) treatment planning system (TPS) software was used to program the plan design. The Swedish Elekta Synergy accelerator 6MV-X-ray (Elekta AB) was irradiated. The 7F-IMRT and VMAT radiotherapy plans were designed according to each case with the same target area. The IMRT plan had 7 fields coplanar radiated fields, with incident angles at 0˚, 51˚, 102˚, 154˚, 205˚, 256˚, and 307˚; the VMAT plan had a 3,600 single arc; and the ISO point was set in the geometric centre of the PTV, of which the dose limited levels were measured for small intestine and bladder. The prescription dose was 50 and 2 Gy per time, 5 times per week, and minimum standards were set: Isodose line of 95% prescription dose included 100% PTV, the highest dose <110-115% of the prescription dose, high dose area did not include the small intestine and stump rectum; while the normal tissue had a limited dose: Small intestine D_{max} was ≤45-50 Gy, D_{50} was ≤20-30 Gy; and for the bladder the limited dose D_{50} was ≤50 Gy; and bilateral femoral bones D_5 was ≤50 Gy.

Evaluation index. Using the Monaco CMS (3.0 edition, Sweden) TPS was utilized to evaluate the two radiotherapy plans. The first plan involved differences in target dose distribution, homogeneity index (HI), conformal index (CI), while the target and endangered organ dose volume of the two types of treatment plans were compared with the dose volume histogram. For the CI, the dose curve and target area conformity were evaluated and defined as (VPTV95%/VPTV) x (VPTV95%/VT), where VPTV95% was the PTV volume involved by the 95% isodose line. VPTV was the total volume of PTV, where VT was the irradiated volume covered by the 95% isodose line, and the CI values closer to l represented a scheme. HI reflects the homogeneity of the dose distribution in the target area, defined as D_5/D_{95}, D_5 was the lowest dose of the 5% target volume accepted by high-dose irradiation, and D_{95} referred to the lowest dose of 95% target volume accepted. HI values closer to 1 indicated better uniformity. HICTV and HIPTV were used to evaluate dose uniformity of the CTV and PTV target area, respectively. The evaluation index of endangered organs involved was assessed as follows: Intestinal V10, V15, V20, V30, S40, V50; bladder V20, V30, S40, V50; and caput femoris V40, V45, V50, where Vx represented the proportion of the volume irradiated by X-Gy accounting for the entire volume (%). The machine unit (MU) was evaluated.

Table I. IMRT and VMAT plan target volume dose comparison (mean ± standard deviation).

Plan types	CI	HI
7F-IMRT	0.8319±0.0143	1.0760±0.0179
VMAT	0.8380±0.0164	1.0821±0.0143
t value	2.218	-2.228
P-value	0.054	0.053

7F-IMRT, 7-field intensity modulated; VMAT, volume intensity modulated radiation therapy; CI, conformal index; HI, homogeneity index.

Statistical analysis. Statistical analysis was performed with SPSS 20.0 statistical software (Chicago, IL, USA). The differences of various parameters between the two groups were analyzed and compared with paired sample average t test. $P<0.05$ was considered to indicate a statistically significant difference.

Results

Dose distribution of target area: Comparison of target volume dose between IMRT and VMAT plan. Dose distributions of the IMRT and VMAT plan were similar, the target coverage met the requirements of the prescription dose and both plans reached up to the 95% isodose line at a volume of 100% PTV. There was no statistical difference between CI and HI in either of the two plans (Table I).

Dose distribution of small intestine, bladder and in caput femoris. Comparisons of small intestine dose and volume of the IMRT and VMAT plans are shown in Table II. V40 and V50 dose plans were better with the VMAT as compared to IMRT (Table II). Furthermore, in bladder, the volume radiated by the dose of the IMRT plan was better in all respects in comparison with the VMAT plan (Table III). However, in the caput femoris, the two plans did noshowed any statically significant difference (Table IV).

Comparison of MU. The MUs showed statistically significant decrease in VMAT plan in comparison with the IMRT plan (Table V).

Discussion

The morbidity of colorectal cancer is on the rise, and the incidence of global common malignant tumors is ranked third. Local recurrence after the resection of rectal cancer is an important cause of failure in the treatment of rectal cancer (1,2). The recurrence rate of stage II-III of rectal cancer

Table II. Comparison of small intestine dose and volume in IMRT plan and VMAT plan (mean ± standard deviation).

Plan types	V10	V15	V20	V30	V40	V50
7F-IMRT	64.70±10.13	54.2±13.01	44.7±11.04	32.35±7.82	12.76±4.85	8.33±4.15
VMAT	75.30±9.67	60.40±16.50	49.00±12.82	33.30±7.39	11.38±4.10	5.55±2.75
t-value	10.70	4.764	3.662	2.390	-4.659	-6.19
P-value	0.000	0.001	0.005	0.041	0.001	0.000

7F-IMRT, 7-field intensity modulated radiation therapy technology; VMAT, volumetric modulated arc therapy.

Table III. Comparison of bladder dose volume in IMRT and VMAT plans (mean ± standard deviation).

Plan types	V20	V30	V40	V50
IMRT	76.90±8.95	70.2±8.87	54.40±7.34	30.80±8.49
VMAT	92.00±5.01	71.60±9.22	56.6±7.40	36.50±10.67
t-value	-9.23	-3.10	-3.49	-5.20
P-value	0.000	0.013	0.007	0.001

IMRT, intensity modulated radiation therapy technology; VMAT, volumetric modulated arc therapy.

Table IV. Comparison of caput femoris dose volume in IMRT and VMAT plans (mean ± standard deviation).

Plan types	V30	V40	V50
IMRT	15.7270±6.2857	2.0160±0.1823	0.5870±0.3710
VMAT	13.1390±4.6369	1.8280±0.2672	0.1670±0.1944
t-value	-4.697	-4.602	-5.372
P-value	0.001	0.001	0.00

IMRT, intensity modulated radiation therapy technology; VMAT, volumetric modulated arc therapy.

Table V. Comparison of machine unit in IMRT and VMAT plans (MU mean ± standard deviation).

Plan types	Average MU value
IMRT	793.20±56.62
VMAT	594.10±36.06
t-value	-30.20
P-value	0.000

The two plans were compared, MU in VMAT plan was less, there was statistical difference. MU, machine unit; VMAT, volumetric modulated arc therapy; IMRT, intensity modulated radiation therapy technology.

after radical resection is ~30%; thus, radiotherapy combined with chemotherapy after resection of rectal carcinoma is one of the standard treatments. Rectal cancer surgery usually results in significant changes in the pelvic anatomy. Consequently, postoperative radiotherapy increases the irradiated volume, and the part of the bladder near the target area becomes affected by irradiation. In recent years, it has been shown that IMRT technology improved the dose distribution of the target area, and better protected normal tissue (3). VMAT is another upcoming technology involving rotating IMRT technology that continuously and dynamically adjusted the machine frame speed, dose rate and field shape of the radiation (4). VMAT combines dynamic multi-leaf collimator technology with the machine frame rotation, radiating in the process of the machine frame rotation. The machine frame rotation speed is 3,600, and the maximum dose rate was ≤600 MU/min. Thus, it has the ability to complete a clinical procedure in a short duration of time with static IMR (5). In comparison to IMRT techniques, the VMAT improves the biological effects of the target area and increases the number of treated patients within unit time at the same time (6). Moreover, in VMAT there is a significant reduction of MU, which helps in the reduction of the amount of machine head-scattered rays (7-9). VMAT is effective in the treatment of tumors of head and neck, chest, abdomen and other parts of the body (8,10-12). Stieler *et al* study showed that VMAT technology had the advantage in CI of patients with anal cancer compared with 3D-CRT technology (13). Yoo *et al* (14) compared dosimetric differences between FF, IMRT and VMAT of prostate cancer and found that the D_{mean} of rectum, bladder, and small intestine decreased ~3.6, 4.8 and 3.1%, respectively. Vanetti *et al* (15) analyzed the dosimetric differences of head and neck tumors and found that D_{mean} of the parotid gland decreased from 40 to 34 Gy with VMAT.

The present study compared the dosimetric characteristics of intensity modulated radiation therapy of IMRT and VMAT. The results showed that the two types of intensity modulated plans met the requirement of the target prescription dose, and

CI and HI were not statistically significant when compared, with regard to the PTV dose (3). The small intestine was the main dose-limiting organ of rectal carcinoma radiation therapy. The incidence of adverse reaction of the intestinal tract was closely related to the intestinal irradiation dose and volume. The study observed that when the intestine was radiated with large volume or high dose, gastrointestinal symptoms appeared easily, such as serious intestinal adhesion, intestinal obstruction, and even intestinal perforation (16). The comparative analyses of the two plans showed that the V40 and V50 of the small intestine in VMAT planning were lower than IMRT, which is of great significance for the protection of small intestine. At the same time, we found that the irradiation volume and average dose of bladder with high dose in VMAT were also significantly reduced. The number of MUs and the duration of treatment were positively correlated, with VMAT being shorter in treatment time in comparison to IMRT. This could increase the number of patients treated by each machine, which in turn helped in the reduction of the irradiation risks due to lower comfort levels.

The present study concludes that after resection of rectal cancer, patients treated by VMAT techniques obtained equal or superior dose distribution compared with the IMRT plan. Unwanted exposure to the small intestine was significantly reduced in the VMAT technique. Moreover, the treatment time was less in the VMAT technique. Collectively, it is evident that VMAT is a far better option for use than IMRT.

References

1. Zhang Z: Progress of adjuvant radiotherapy and clinical research of rectal cancer. Chin J Cancer 16: 417-420, 2006.
2. Liu HP, Ichikawa Y, Nagano Y and Shiono S: Surgery for colorectal cancer lung metastases. Asian Pac J Surg Oncol 2: 183-192, 2016.
3. Zhang F, Chen J and Chen J: Dosimetric comparison between bone marrow-sparing intensity-modulated radiotherapy and conventional intensity-modulated radiotherapy for cervical cancer. Chinese Journal of Radiation Oncology 19: 37-39, 2010.
4. Cilla S, Caravatta L, Picardi V, Sabatino D, Macchia G, Digesù C, Deodato F, Massaccesi M, De Spirito M, Piermattei A *et al*: Volumetric modulated arc therapy with simultaneous integrated boost for locally advanced rectal cancer. Clin Oncol (R Coll Radiol) 24: 261-268, 2012.
5. Otto K: Volumetric modulated arc therapy: IMRT in a single gantry arc. Med Phys 35: 310-317, 2008.
6. Teoh M, Clark CH, Wood K, Whitaker S and Nisbet A: Volumetric modulated arc therapy: A review of current literature and clinical use in practice. Br J Radiol 84: 967-996, 2011.
7. Hall EJ: Intensity-modulated radiation therapy, protons, and the risk of second cancers. Int J Radiat Oncol Biol Phys 65: 1-7, 2006.
8. Jin X, Yi J, Zhou Y, Yan H, Han C and Xie C: Comparison of whole-field simultaneous integrated boost VMAT and IMRT in the treatment of nasopharyngeal cancer. Med Dosim 38: 418-423, 2013.
9. Seco J, Gu G, Marcelos T, Kooy H and Willers H: Proton arc reduces range uncertainty effects and improves conformality compared with photon volumetric modulated arc therapy in stereotactic body radiation therapy for non-small cell lung cancer. Int J Radiat Oncol Biol Phys 87: 188-194, 2013.
10. Myrehaug S, Chan G, Craig T, Weinberg V, Cheng C, Roach M III, Cheung P and Sahgal A: A treatment planning and acute toxicity comparison of two pelvic nodal volume delineation techniques and delivery comparison of intensity-modulated radiotherapy versus volumetric modulated arc therapy for hypofractionated high-risk prostate cancer radiotherapy. Int J Radiat Oncol Biol Phys 82: e657-e662, 2012.
11. Kopp RW, Duff M, Catalfamo F, Shah D, Rajecki M and Ahmad K: VMAT vs. 7-field-IMRT: Assessing the dosimetric parameters of prostate cancer treatment with a 292-patient sample. Med Dosim 36: 365-372, 2011.
12. Quan EM, Li X, Li Y, Wang X, Kudchadker RJ, Johnson JL, Kuban DA, Lee AK and Zhang X: A comprehensive comparison of IMRT and VMAT plan quality for prostate cancertreatment. Int J Radiat Oncol Biol Phys 83: 1169-1178, 2012.
13. Stieler F, Wolff D, Lohr F, Steil V, Abo-Madyan Y, Lorenz F, Wenz F and Mai S: A fast radiotherapy paradigm for anal cancer with volumetric modulated arc therapy (VMAT). Radiat Oncol 4: 48-69, 2009.
14. Yoo S, Wu QJ, Lee WR and Yin FF: Radiotherapy treatment plans with RapidArc for prostate cancer involving seminal vesicles and lymph nodes. Int J Radiat Oncol Biol Phys 76: 935-942, 2010.
15. Vanetti E, Clivio A, Nicolini G, Fogliata A, Ghosh-Laskar S, Agarwal JP, Upreti RR, Budrukkar A, Murthy V, Deshpande DD *et al*: Volumetric modulated arc radiotherapy for carcinomas of the oro-pharynx, hypo-pharynx and larynx: A treatment planning comparison with fixed field IMRT. Radiother Oncol 92: 111-117, 2009.
16. Wang JZ, Li XA, D'Souza WD and Stewart RD: Impact of prolonged fraction delivery times on tumor control: A note of caution for intensity-modulated radiation therapy (IMRT). Int J Radiat Oncol Biol Phys 57: 543-552, 2003.