Original Article

Implementation of Constant Dose Rate and Constant Angular Spacing Intensity-modulated Arc Therapy for Cervical Cancer by Using a Conventional Linear Accelerator

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Abstract

Background: Volumetric-modulated arc therapy (VMAT) can only be implemented on the new generation linacs such as the Varian Trilogy® and Elekta Synergy®. This prevents most existing linacs from delivering VMAT. The purpose of this study was to investigate the feasibility of using a conventional linear accelerator delivering constant dose rate and constant angular spacing intensity-modulated arc therapy (CDR-CAS-IMAT) for treating cervical cancer.

Methods: Twenty patients with cervical cancer previously treated with intensity-modulated radiation therapy (IMRT) using Varian Clinical 23EX were retreated using CDR-CAS-IMAT. The planning target volume (PTV) was set as 50.4 Gy in 28 fractions. Plans were evaluated based on the ability to meet the dose volume histogram. The homogeneity index (HI), target volume conformity index (CI), the dose to organs at risk, radiation delivery time, and monitor units (MUs) were also compared. The paired *t*-test was used to analyze the two data sets. All statistical analyses were performed using SPSS 19.0 software.

Results: Compared to the IMRT group, the CDR-CAS-IMAT group showed better PTV CI (0.85 ± 0.03 vs. 0.81 ± 0.03, $P = 0.001$), clinical target volume CI (0.46 ± 0.05 vs. 0.43 ± 0.05, $P = 0.001$), HI (0.09±0.02 vs. 0.11 ± 0.02, $P = 0.005$) and D95 (5196.33 ± 28.24 cGy vs. 5162.63 ± 31.12 cGy, $P = 0.000$), and cord D2 (3743.8 ± 118.7 cGy vs. 3806.2 ± 98.7 cGy, $P = 0.017$) and rectum V40 (41.9 ± 6.1% vs. 44.2 ± 4.8%, $P = 0.026$). Treatment time (422.7 ± 46.7 s vs. 84.6 ± 7.8 s, $P = 0.000$) and the total plan Mus (927.4 ± 79.1 vs. 787.5 ± 78.5, $P = 0.000$) decreased by a factor of 0.8 and 0.15, respectively. The IMRT group plans were superior to the CDR-CAS-IMAT group plans considering decreasing bladder V50 (17.4 ± 4.5% vs. 16.6 ± 4.2%, $P = 0.049$), bowel V30 (39.6 ± 6.5% vs. 36.6 ± 7.5%, $P = 0.008$), and low-dose irradiation volume; there were no significant differences in other statistical indexes.

Conclusions: Patients with cervical cancer treated with CDR-CAS-IMAT using Varian Clinical 23EX can get equivalent or superior dose distribution compared to those treated with IMRT. CDR-CAS-IMAT has a less treatment time and MU, which can reduce the uncertainty factor and patient discomfort in treatment.

Key words: Cervical Cancer; Constant Angular Space; Constant Dose Rate; Dosimetry; Intensity-modulated Arc Therapy; Intensity-modulated Radiation Therapy

Introduction

Volumetric-modulated arc therapy (VMAT), the novel form of intensity-modulated radiation therapy (IMRT) that was first pioneered by Yu[1] in 1995, involves a single arc of 360° or less that is delivered under continuous variation of multileaf collimator (MLC) segments, dose rate, and gantry speed. It was first introduced by Otto[2] in 2008, and the newly introduced VMAT (Elekta VMAT and Varian RapidArc®) has gained worldwide interest in both research and clinical implementation owing to its superior plan quality and delivery efficiency. Various treatment planning studies have been performed, comparing VMAT and static IMRT with regard to plan quality, delivery time, and monitor units (MUs) required per fraction dose. These studies have generally shown that VMAT delivery has similar or better dose distributions

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and speed over step-and-shoot IMRT[3,4] and a reduction in MUs.[2,5,6] Alternatively, the VMAT technique promises dosimetric benefits for a wide range of disease sites, including the head and neck, rectum, prostate, or whole abdominopelvic cavity.[7-10] This improvement is important for patient compliance considering comfort and treatment duration, as well as follow-up. However, these new techniques involve rotating irradiation at a variable dose rate and gantry speed is required, allowing the aperture weights to vary at different beam angles. Because the variable dose rate and gantry speed requirements complicate the control hardware and software of the linear accelerators (linacs), this technology can only be achieved in the new generation accelerators such as the Varian RapidArc® and Elekta Synergy®, which prevents most existing linacs from being used for delivering VMAT.

Zhang *et al*.[11] proposed an alternative planning approach for VMAT by using constant dose rate and constant gantry speed arc therapy with the conventional Linac Varian 23EX for thoracic esophageal carcinoma; the results showed that the treatment time compared with the IMRT technology decreased significantly and reached 62.9%. Considering that the target volume shape of esophageal cancer is usually cylindrical and that postoperative patients with cervical cancer usually have a large and concave target volume, treatment with IMRT is time-consuming.

The purpose of this study was to investigate the use of constant dose rate and constant angular spacing intensity-modulated arc therapy (CDR-CAS-IMAT) with conventional linacs for postoperative patients with cervical cancer. As there have been many studies on IMRT using multiple intensity-modulated fields, a planning study was performed to evaluate the performance of CDR-CAS-IMAT for postoperative patients with cervical cancer. Using conventional fixed-field IMRT as a benchmark, comparisons between CDR-CAS-IMAT and IMRT were made considering planning, delivery, and quality assurance. In addition, dosimetry evaluation was performed, thereby providing guidance for clinical treatment.

Methods

Clinical data

Twenty patients with cervical cancer who were treated with IMRT on Varian Clinical 23EX between January 2013 and December 2013 in the Fourth Hospital of Hebei Medical University were enrolled in this study. All selected patients had previously undergone surgery. This study was approved by the Institutional Review Board of Hebei Medical University and was performed in accordance with the ethical standards of human experimentation and the *Declaration of Helsinki*. Patients who were scheduled to undergo radiotherapy underwent computed tomography (CT), and the CT scanning image sequences were imported in the treatment planning system. The planning target volumes (PTVs) and organs at risk (including the small intestine, rectum, bladder, colon, and the left and right femoral head) were contoured by experienced doctors. The patients received treatment with CDR-CAS-IMAT using a conventional linac of Varian Clinical 23EX (Varian Medical Systems, Inc., Palo Alto, USA) equipped with a Millennium MLC with 120 leaves, with a spatial resolution of 5 mm at the isocenter. The PTV was set as 50.4 Gy in 28 fractions. The planning objectives for PTVs were corresponding with the IMRT plans until at least 95% PTV reached the prescription dose and the V110 was no more than 10%. The maximum dose to the spinal cord was limited to 40 Gy, and the V40 and versus for the rectum and bladder were corresponding with the IMRT plans until at least 95% PTV was reached. All plans were evaluated based on the ability to meet the dose volume histogram (DVH). The homogeneity index (HI), conformity index (CI) of the target volume, the dose to the organs at risk, radiation delivery time, and MUs were compared. In addition, all the plans were optimized by a single planner.

Intensity-modulated radiation therapy and constant dose rate and constant angular spacing intensity-modulated arc therapy planning

All the plans were prepared using the Oncentra Planning System version 4.1 (Elekta Inc., Stockholm, Sweden), which supports VMAT optimization; they were generated for 6-MV photons, with the maximum dose rate maintained at 600 MU/min. The collimator and the treatment couch were set at 0 for all the plans. IMRT plans were designed using seven gantry angles, i.e., 257°, 308°, 0°, 51°, 103°, 154°, and 206°. The optimization parameters adopted were recommended by Qiu *et al*.,[12] i.e., the minimum segment area of 7 cm × 7 cm, the minimum segment MU of 5, and the maximum number of segments of <55. All the CDR-CAS-IMAT treatment plans consisted of only a single arc with 358° gantry rotation. The arc was planned in the clockwise direction from 181° to 179°, the dose rate was constant (set at 500 MU/min), and the gantry rotation velocity was constant set at 6°/s.

Evaluation tools

The plans were evaluated using a standard DVH. For PTV, D98% and D2% (dose received by the 98% and 2% of the volume, respectively) were defined as the minimum and maximum doses, respectively. The homogeneity of the treatment plans was expressed as (D2–D98%)/D50% (HI) according to ICRU 83.[13] A HI of 0 indicates that the absorbed dose distribution is almost homogeneous. The conformity of the plans was measured using the CI, calculated as the ratio between the volume of the reference isodose ($V_{95\%}$) and the PTV volume (V_{PTV}, $V_{95\%}/V_{PTV}$).[14] $V_{95\%}$ was defined as the volume receiving at least 95% of the prescribed dose. For organs at risk, the analysis includes the mean dose and the maximum dose. For normal tissue, E-P was defined as the integral of the absorbed dose extended over all voxels, but excluding those within the PTV. In addition, patient-specific quality assurance for all the treatment plans (both IMRT and CDR-CAS-IMAT) was done using the Delta4 phantom (ScandiDos, Uppsala, Sweden) with 1069 diodes. Gamma analysis (±3 mm, ±3%) was used to evaluate the accuracy of CDR-CAS-IMAT delivery. The acceptance criteria of 3 mm for the distance to agreement and the dose difference tolerance level of 3% were chosen for analysis. In addition, the percentage of the evaluated dose points passing the gamma index was kept at a limit of ≥95%.

Statistical analysis

The baseline characteristics are presented as mean ± standard deviation (SD). The paired *t*-test was used to analyze the two sets of data. A *P* value of <0.05 was considered statistically significant. All statistical analyses were performed using SPSS 19.0 software (SPSS Inc., Chicago, IL, USA).

Results

All plans sufficiently conformed to the planning objectives and were clinically acceptable. Tables 1 and 2 provide an overview of the numerical findings from an average DVH analysis of the PTV and healthy tissues (E-P), which assessed for inter-patient variability. Both the delivery techniques appear to be equivalent when considered from a clinical perspective. Figure 1 shows the planned treatment dose for CDR-CAS-IMAT and IMRT. Figure 2 shows the DVH. From the analysis results shown in Tables 1 and 2, CDR-CAS-IMAT plans have equivalent or superior quality compared to IMRT plans, while small deviations were observed in the volume of irradiated 40 Gy for the bladder and the volume of irradiated 30 Gy for the bowel.

Delivery times were measured by using an automatic field sequence in the recording and verifying IMPAC Medical systems (Electa Inc. Stockholm, Sweden). The doses delivered were measured utilizing the Delta4 phantom with 1069 diodes. The number of MU and the delivery time were significantly lower for the CDR-CAS-IMAT plan than those for the IMRT plan. Compared with IMRT plan, treatment times were reduced significantly (422.7 ± 46.7 s vs. 84.6 ± 7.8 s, $t = -36.00$, $P = 0.000$) and the total plan MUs decreased by a factor of 0.15 (927.4 ± 79.1 vs. 787.5 ± 78.5, $t = -6.26$, $P = 0.000$) for CDR-CAS-IMAT plan. Both techniques had equally high accuracy in the dose delivery considering the high rates (>95%) of detectors passing the gamma index criterion (±3 mm, ±3%) [Table 3]. On comparison of the CDR-CAS-IMAT and IMRT plans, we observed an increased E-P low-dose area volume and decreased height dose area. There was no significant difference in E-P V20 Gy and Delta4 measurements results between both the planning techniques (all $P > 0.05$).

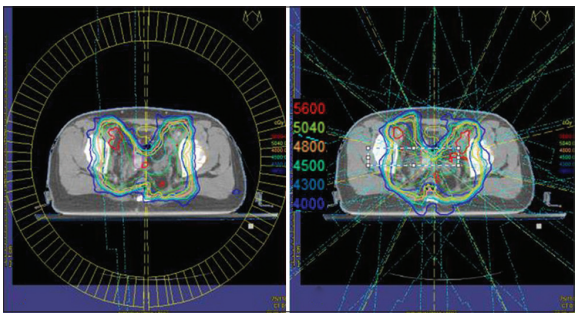

Figure 1: Dose distributions in a transverse slice for constant dose rate and constant angular spacing intensity-modulated arc therapy and intensity-modulated radiation therapy plans of a case. The dose lines are depicted with a thick solid line: 56 Gy (red), 50.4 Gy (yellow), 48 Gy (orange), 45 Gy (green), 43 Gy (blue), and 40 Gy (dark blue).

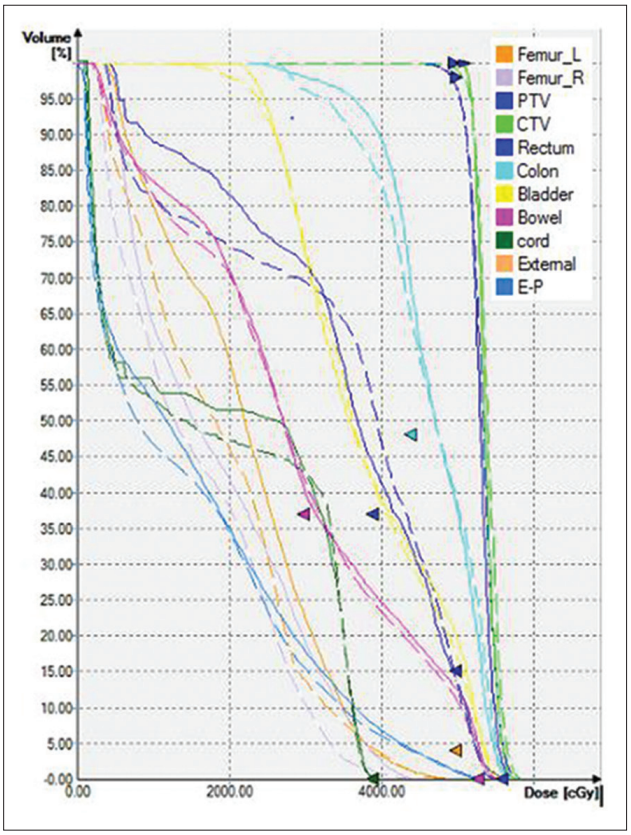

Figure 2: Dose volume histograms for the target volume and organs at risk for constant dose rate and constant angular spacing intensity-modulated arc therapy and intensity-modulated radiation therapy. Dose volume histograms for planning target volume, clinical target volume, and organs at risk for constant dose rate and constant angular spacing intensity-modulated arc therapy (solid line) and intensity-modulated radiation therapy (dashed line).

Table 1: Dosimetric parameters comparison of CDR-CAS-IMAT and IMRT plans considering the target volume

Plans	HI (PTV)	CI (PTV)	HI (CTV)	CI (CTV)	D95 (CTV) (cGy)	D98 (CTV) (cGy)	V98 (CTV) (%)	V100 (CTV) (%)
CDR-CAS-IMAT	0.12 ± 0.02	0.85 ± 0.03	0.09 ± 0.02	0.46 ± 0.05	5196.33 ± 28.24	5153.40 ± 21.21	99.9 ± 0.13	5233.98 ± 34.32
IMRT	0.13 ± 0.02	0.81 ± 0.03	0.11 ± 0.02	0.43 ± 0.05	5162.63 ± 31.12	5093.54 ± 35.02	99.0 ± 0.59	5216.69 ± 31.81
t	−1.35	3.87	−3.20	4.23	4.68	7.80	6.04	2.15
P	0.194	0.001	0.005	0.001	0.000	0.000	0.000	0.049

Data are shown as mean ± SD. SD: Standard deviation; CDR-CAS-IMAT: Constant dose rate and constant angular spacing intensity-modulated arc therapy; IMRT: Intensity-modulated radiation therapy; PTV: Planning target volume; CTV: Clinical target volume; HI: Homogeneity index; CI: Conformity index; D95 is the minimum dose received by the 95% of the volume, D98, and so on; V98 is the volume of the target volume irradiated at 98% prescription dose, V100, and so on.

Table 2: Dosimetric parameters comparison of CDR-CAS-IMAT and IMRT plans considering organs at risk

Plans	Cord D2 (cGy)	Rectum V40 (%)	Bladder V50 (%)	Bowel V30 (%)
CDR-CAS-IMAT	3743.8 ± 118.7	41.9 ± 6.1	17.4 ± 4.5	39.6 ± 6.5
IMRT	3806.2 ± 98.7	44.2 ± 4.8	16.6 ± 4.2	36.6 ± 7.5
t	–2.70	–2.50	2.20	3.00
P	0.017	0.026	0.049	0.008

Data are shown as mean ± SD. SD: Standard deviation; CDR-CAS-IMAT: Constant dose rate and constant angular spacing intensity-modulated arc therapy; IMRT: Intensity-modulated radiation therapy; D2 is the minimum dose received by 2% of the volume; V40 is the percentage of the dose equal to or more than 40 Gy volume to the total volume, V50, V30, and so on.

Table 3: Dosimetric parameters comparison of CDR-CAS-IMAT and IMRT plans in healthy tissues (%)

Plans	E-P (V5)	E-P (V10)	E-P (V15)	E-P (V20)	E-P (V50)
CDR-CAS-IMAT	49.7 ± 9.6	42.0 ± 8.0	34.8 ± 6.7	27.2 ± 5.2	0.7 ± 0.2
IMRT	45.9 ± 9.1	37.6 ± 7.4	33.5 ± 6.5	26.7 ± 5.0	1.0 ± 0.3
t	16.40	21.20	6.50	2.0	–3.80
P	0.000	0.000	0.000	0.062	0.001

Data are shown as mean ± SD. SD: Standard deviation; CDR-CAS-IMAT: Constant dose rate and constant angular spacing intensity-modulated arc therapy; IMRT: Intensity-modulated radiation therapy; E-P: The body volume minus the volume of planning target volume on computed tomography; V5 is the percentage of accepting dose equal to or more than 5 Gy volume to the total volume, V10, V15, V20, V50, and so on.

Discussion

VMAT can provide superior target volume coverage and conformity, with decreased dose to organs at risk for abdominal tumors.[9,10] A dosimetric comparison between VMAT and IMRT for cervical cancer demonstrated that VMAT reduced treatment time and delivered MUs.[15,16] However, VMAT can only be implemented using the new generation linacs such as the Varian RapidArc® and Elekta Synergy®, because the requirement for variable dose rate complicates the control hardware and software of the linacs and prevents most existing linacs from delivering VMAT. The other reason why VMAT cannot be performed using the older generation of linacs is that these machines do not have a secondary readout for the gantry position. While for IMRT, this is not a problem because gantry position can be checked on the mechanical scale of the linac. This is not possible during VMAT treatments and a malfunction of the gantry readout can lead to a wrong position of the gantry.

Tang *et al*.[17] suggested using variable angular spacing, CDR of RapidArc plans can be implemented in the clinics that are not equipped with the new variable dose rate-enabled machines without compromising the plan quality or treatment efficiency. A previous study suggested the development of an application[11] that proposes an alternative planning approach for VMAT using constant dose rate and gantry speed arc therapy implementation with conventional linac Varian Clinical 23EX for thoracic esophageal carcinoma; the results showed that the treatment times decreased significantly and can reach 62.9%. For CDR-CAS-IMAT, which uses a 360° rotating cast that can provide powerful strength to adjust the degree of freedom, the variables of the optimization depend on each incident direction of the leaf position (open field), while for IMRT, radiation field irradiation is considered only in a fixed angle of incidence direction for MLC position optimization. From the degrees of freedom according to the optimization choice, the number of optimized CDR-CAS-IMAT rays far outweighs that of IMRT; therefore, the CDR-CAS-IMAT plans are relatively easier to implement for highly uniform target doses and for protecting normal tissue from the high-dose irradiation area.

The results of our study showed that CDR-CAS-IMAT plan for postoperative cervical cancer can meet the clinical demand and give comparable HI and better CI of PTV. In addition, all the clinical target volume indicators of the CDR-CAS-IMAT plans are superior to those of IMRT [Table 1]. Moreover, CDR-CAS-IMAT plans can decrease the treatment time, MU, and high-dose irradiated volume, while increasing the low-dose irradiated volume of healthy tissues and the volume of the bladder and bowel irradiated at 40 Gy and 30 Gy, respectively. This advantage was because of the characteristic of CDR-CAS-IMAT that involves 358° of rotation therapy, which can otherwise endanger organs and normal tissue that are relatively far away from the target area to accept an increase in the volume of low-dose irradiation. On the other hand, IMRT plan have only fixed beams that can avoid some normal tissues in the irradiation area, so that the normal tissues in the low-dose irradiation area will be slightly less. Seven-field IMRT plans have many sub-fields and the transformation time is relatively long, and generally, the machine MU of the sub-field is approximately between 6 and 16 MU; the treatment accelerator may not reach the calibration dose rate or it may just reach the set dose rate when the beam is stopped. Compared to the IMRT plans, the CDR-CAS-IMAT plans that are delivered at a CDR of 500 MU/min will be more stable and avoid the multiple sub-field beams, avoiding the introduction of dose rate error.

In the present study, the biggest advantages of CDR-CAS-IMAT were the overall treatment time and the delivery dose of 1.8 Gy with a single arc gantry rotation time of approximately 85 s, compared with IMRT treatment time of 423 s (the treatment time decreased by 80%). In general, patients can complete treatment in 1–2 min; the low treatment time can effectively reduce the risk of patient movement, organ volume change and movement, and other uncertainties, as well as increase the biological effects. Wang *et al*.[18] reported that prolonged fraction delivery times could decrease the treatment outcome, especially for tumors with a low α/β ratio and short repair half-time. In a study by Moiseenko *et al*.,[19] irradiation three strains *in vitro* cell clusters, delivered time was 75 s, 5 min, 10 min, and the results showed that the

survival rate of cervical cancer cell was 39%, 53%, and 59%, respectively. The obtained data set can serve as a reference data set for theoretical studies designed to elucidate the role of dose delivery prolongation in IMRT as it may affect treatment outcome. Whether the change of tumor *in vivo* is consistent with the change of cell clusters needs further study. As stated above, the disadvantage of CDR-CAS-IMAT plan is the increased low-dose irradiated area that can increase the secondary carcinogenic probability,[20] thereby affecting the life expectancy of patients.[21] This should be noted in the clinical treatment.

In conclusion, postoperative patients with cervical cancer treated with CDR-CAS-IMAT using the conventional linac Varian Clinical 23EX can get equivalent or superior dose distribution, compared to IMRT; CDR-CAS-IMAT also has a lesser delivery time and MU, which can reduce the uncertainty factor and patient discomfort in treatment. The clinical application of CDR-CAS-IMAT technology for the treatment of postoperative cervical cancer is feasible, and it can be promoted as a new way of irradiation.

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Conflicts of interest

There are no conflicts of interest.

References

1. Yu CX. Intensity-modulated arc therapy with dynamic multileaf collimation: An alternative to tomotherapy. Phys Med Biol 1995;40:1435-49. doi: 10.1088/0031-9155/40/9/004.
2. Otto K. Volumetric modulated arc therapy: IMRT in a single gantry arc. Med Phys 2008;35:310-7. doi: 10.1118/1.2818738.
3. Shepard DM, Cao D, Afghan MK, Earl MA. An arc-sequencing algorithm for intensity modulated arc therapy. Med Phys 2007;34:464-70. doi: 10.1118/1.2409239.
4. Earl MA, Shepard DM, Naqvi S, Li XA, Yu CX. Inverse planning for intensity-modulated arc therapy using direct aperture optimization. Phys Med Biol 2003;48:1075-89. doi: 10.1088/0031-9155/48/8/309.
5. Wang C, Luan S, Tang G, Chen DZ, Earl MA, Yu CX. Arc-modulated radiation therapy (AMRT): A single-arc form of intensity-modulated arc therapy. Phys Med Biol 2008;53:6291-303. doi: 10.1088/0031-9155/53/22/002.
6. Yu CX, Amies CJ, Svatos M. Planning and delivery of intensity-modulated radiation therapy. Med Phys 2008;35:5233-41. doi: 10.1118/1.3002305.
7. Bertelsen A, Hansen CR, Johansen J, Brink C. Single arc volumetric modulated arc therapy of head and neck cancer. Radiother Oncol 2010;95:142-8. doi: 10.1016/j.radonc.2010.01.011.
8. Palma D, Vollans E, James K, Nakano S, Moiseenko V, Shaffer R, *et al.* Volumetric modulated arc therapy for delivery of prostate radiotherapy: Comparison with intensity-modulated radiotherapy and three-dimensional conformal radiotherapy. Int J Radiat Oncol Biol Phys 2008;72:996-1001. doi: 10.1016/j.ijrobp.2008.02.047.
9. Duthoy W, De Gersem W, Vergote K, Coghe M, Boterberg T, De Deene Y, *et al.* Whole abdominopelvic radiotherapy (WAPRT) using intensity-modulated arc therapy (IMAT): First clinical experience. Int J Radiat Oncol Biol Phys 2003;57:1019-32. doi: 10.1016/S0360-3016(03)00663-1.
10. Duthoy W, De Gersem W, Vergote K, Boterberg T, Derie C, Smeets P, *et al.* Clinical implementation of intensity-modulated arc therapy (IMAT) for rectal cancer. Int J Radiat Oncol Biol Phys 2004;60:794-806. doi: 10.1016/j.ijrobp.2004.04.016.
11. Zhang R, Fan X, Bai W, Han C. Implementation of constant dose rate and gantry speed arc therapy (CDR-CAS-IMAT) for thoracic esophageal carcinoma on Varian 23EX. Med Phys 2014;41:14. doi: 10.1118/1.4894895.
12. Qiu R, Wang Y, Cao Y, Zhang R, Shang K, Chi Z. Relationship between dose of distribution and area of segment fields among different intensity-modulated radiotherapy planning in cervix cancer. Med Phys 2014;41:364. doi: 10.1118/1.4888928.
13. ICRU. Prescribing, recording, and reporting photon-beam intensity-modulated radiation therapy (IMRT). J ICRU 2010;10:35. doi: 10.1093/jicru/ndq002.
14. Feuvret L, Noël G, Mazeron JJ, Bey P. Conformity index: A review. Int J Radiat Oncol Biol Phys 2006;64:333-42. doi: 10.1016/j.ijrobp.2005.09.028.
15. Guozi Y, Zhenyu P, Wenming X, Yinghua S, Huafang W, Lihua D. Dosimetric comparison and clinical application of RapidArc and intensity-modulated radiotherapy for postoperative radiotherapy of cervical cancer. Chin J Raiol Med Prot 2014;31:37-40. doi: 10.3760/cma.j.issn.0254-5098.2014.01.010.
16. Bo Y, Tingtian P, Xiansong S, Ke H, Jie Q, Fuqua Z. Dosimetric study of volumetric intensity-modulated arc therapy and fixed field intensity-modulated radiotherapy for cervix cancer. Chin J Radiat Oncol 2012;21:543-5. doi: 10.3760/cma.j.issn.1004-4221.2012.06.018.
17. Tang G, Earl MA, Yu CX. Variable dose rate single-arc IMAT delivered with a constant dose rate and variable angular spacing. Phys Med Biol 2009;54:6439-56. doi: 10.1088/0031-9155/54/21/001.
18. Wang JZ, Li XA, D'Souza WD, 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 2003;57:543-52. doi: 10.1016/s0360-3016(03)00499-1.
19. Moiseenko V, Duzenli C, Durand RE. *In vitro* study of cell survival following dynamic MLC intensity-modulated radiation therapy dose delivery. Med Phys 2007;34:1514-20. doi: 10.1118/1.2712044.
20. Hall EJ. Intensity-modulated radiation therapy, protons, and the risk of second cancers. Int J Radiat Oncol Biol Phys 2006;65:1-7. doi: 10.1016/j.ijrobp.2006.01.027.
21. Hall EJ, Wuu CS. Radiation-induced second cancers: The impact of 3D-CRT and IMRT. Int J Radiat Oncol Biol Phys 2003;56:83-8. doi: 10.1016/s0360-3016(03)00073-7.