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ORIGINAL ARTICLE

The Effect of Using the Intermediate Dose Calculation Module on Volumetric Modulated Arc Technique Plan Quality in Esophagus Cancer

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OBJECTIVE

There may be differences between optimized dose distributions and calculated dose distributions in the treatment planning system. The intermediate dose calculation (IDC) module, which was developed to eliminate this difference, provides better dose distribution, especially in inhomogeneous structures such as the lung. In the study, it was aimed to investigate the effect of IDC module for esophagus cancer patients.

METHODS

The treatment plans were prepared with the volumetric modulated arc technique (VMAT), with and without IDC module, for ten thoracic and ten abdominal esophagus patients. The conformity index (CI), homogeneity index (HI) values, and critical organ doses obtained from the dose volume histograms of the prepared plans were compared.

RESULTS

The treatment plans created with IDC module give better results for CI and HI values. Especially in patients with thoracic esophagus where inhomogeneity is more intense due to the presence of the lungs, it has been observed that the IDC module provides a more significant decrease in CI (1.256±0.042 vs. 1.233±0.038, p=0.009) and HI (0.126±0.014 vs. 0.086±0.018, p=0.005) values. Heart V_{30}, Spinal Cord D_{max}, and D_{1cc} values were found to be significantly lower.

CONCLUSION

The use of IDC module in VMAT treatment plans of esophagus cancer patients improves the plan quality.

Keywords: Esophagus; intermediate dose calculation module; volumetric modulated arc technique.

Introduction

Esophageal cancer (EC), constituting 1% of all cancer types, is a type of cancer, in which 482,300 cases are reported worldwide every year. Despite its high mortality, it constitutes 7% of gastrointestinal system tumors and its incidence is lower compared to other malignancies. The high mortality rate carries EC to the 6th place among the most common causes of death.[1-3] While it is mostly seen in the Eastern Anatolia Region in Turkey, Iran, Korea, Japan, China, and South Africa which are among the countries, where EC is most common. Excessive hot beverage consumption, alcohol use, and smoking are considered important risk factors for EC.[3,4]

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The choice of treatment modality for EC depends on the stage of the disease. Although surgery is a curative treatment option for EC,[4,5] it cannot be performed because most patients are diagnosed at advanced stage. Therefore, radiotherapy is a good approach in the treatment of EC.[6] The main purpose of radiotherapy is to protect the healthy tissues around the target volume at the maximum extent, while providing a homogeneous dose distribution in the target volume.[6,7] Thanks to the developing technology, volumetric modulated arc therapy (VMAT) technique, which aims to protect healthy organs better than conventional planning techniques, has been developed. This technique is an improved form of the intensity modulated radiotherapy (IMRT) technique. In VMAT technique, the dose rate, the positions and speeds of the multi-leaf collimators change, and the gantry can rotate 360° around the patient. The treatment delivery time in VMAT is shorter compared to IMRT.[7,8]

The treatment planning systems (TPS) employ the algorithms for optimization and dose calculation. First, the optimization is carried out by algorithms that optimize the dose distributions according to the pre-set dose constraints of the target and organs at risk (OARs). These optimization algorithms are used to determine the combination of field shapes and segment weights which achieve the desired planning. Eclipse TPS used separate optimizers with dose-volume optimizer for IMRT and progressive resolution optimizer for VMAT. Recently, the photon optimizer algorithm has been introduced for VMAT and IMRT optimization generated by the dose-volume histogram (DVH) estimation model.[9,10] The final dose distribution is calculated using the more accurate analytical anisotropic algorithm (AAA), which has been shown to be superior in dose calculation for heterogeneous media and small fields.[11]

In the radiation therapy planning process, the final dose calculation obtained by IMRT or VMAT technique differs from the optimal DVH obtained by the optimization process. An intermediate dose calculation (IDC) module has been developed to solve this problem. IDC module ensures the creation of the optimal plan by continuously optimizing to obtain the desired DVH in line with the dose-volume criteria determined by the user.[11,12] There are few studies showing the effect of the IDC module on the plan quality during optimization.

In this study, it was aimed to investigate the effect of using the IDC module during the optimization of VMAT on plan quality for ten thoracic and ten abdominal EC patients. VMAT treatment plans created with and without IDC module were evaluated in terms of dose-volume metrics, conformity index (CI), and homogeneity index (HI).

Materials and Methods

Image Data Acquisition

A total of 20 patients with EC, including ten abdominal and ten thoracic esophagus patients, who received radiotherapy in Istanbul University Oncology Institute included in this study. Patients were set up in supine position with their arms over their heads using a wing board. The patients' computed tomography (CT) image data sets were acquired with 3 mm slice thickness using a Philips Big Bore Brilliance CT scanner. 3DCT image set of 20 patients were transferred to the Varian Eclipse v15.6 TPS for both contouring and planning.

Delineation of Target Volume and OARs

CT, MRI, and PET-CT were used to delineate the target volume by radiation oncologist and radiologist. The target volume and OARs were contoured on the planning CT by same radiation oncologist. The clinical target volume (CTV) included the esophageal tumor, with a margin for microscopic tumor extension, and the adjacent lymph nodes. For the PTV, a 3-dimensional margin of 5 mm was added to the CTV to account for the variability in patient setup, uncertainty in target definition, and organ motion. The lungs, heart, spinal cord, kidneys, and liver were also delineated on the CT image set as OARs. Target and OAR were delineated according to report ICRU 83.[13]

Treatment Planning and Dose Prescription

The treatment plans for abdominal and thoracic esophagus patients were created using VMAT technique in the Varian Eclipse v15.6 TPS by same medical physicist. All plans were generated using 6 MV photon beams from a Varian Trilogy Linac equipped with a Millennium 120-leaf MLC. The prescription dose to PTV was 5040 cGy with 180 cGy/fraction. Dose calculation was carried out with AAA using a calculation grid of 2.5 mm for all treatment plans.

The treatment plans were prepared with two full arc; the gantry angles were adjusted between 181.0° and 179.0° clockwise for the first arc and between 179.0° and 181.0° counter clockwise for the second arc. The couch angle is set to 0°. The collimator angle was defined 30° for first arc and 330° for second arc. The dose rate was chosen as 600 MU/min. First, the plan optimization was performed based on dose-volume

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Table 1 Dose limits for OARs

OAR	Dose constraint
Lung-PTV	V_{20} <20%
Heart	V_{30} <45%
	Mean <26 Gy
Liver	Mean <30-32 Gy
Bilateral kidney	V_{12} <55%
	V_{20} <32%
	V_{23} <32%
	V_{28} <20%
	Mean <15-18 Gy
Spinal cord	D_{max} <45Gy
	D_{1cc} <50 Gy

OAR: Organs at risk; PTV: Planning target volume; Gy: Gray

constraints without IDC module and dose distribution was calculated using AAA. OARs dose limits based on the recommendations of the Quantitative Analyses of Normal Tissue Effects in Clinic are given in Table 1.[14] This plan was saved as an original plan. Then, the original plan was re-optimized with same optimization parameters with IDC module. Dose calculation was made with same dose calculation algorithm. This planning process was carried out for 20 patients. The plan normalization was made that 95% of the PTV received 50.4 Gy.

The DVHs of VMAT plans with and without IDC module for one abdominal and one thoracic esophagus patient are shown in Figures 1 and 2, respectively.

Dosimetric Evaluation

To evaluate the quality of plans, CI value was calculated using Equation (1);

$$CI=\frac{V_{TV}\times V_{TIH}}{(PTV_{PIH})^2} \quad (1)$$

V_{HV} represents the PTV volume, V_{TIH} represents the volume of the 95% isodose line, and PTV_{PIH} represents the target volume covered by the 95% isodose line. [15,16] Plans with a CI=1 are ideal plans. D_2% (near-maximum), D_{98}% (near-minimum), and D_{50}% (median dose) for PTV were recorded through DVH. HI was calculated by the following Equation (2) based on ICRU 83.[13]

$$HI=\frac{(D_2-D_{98})}{D_{50}} \quad (2)$$

where, D_2 represents the dose received by 2% of PTV, D_{98} represents the dose received by 98% of PTV, and D_{50} represents the dose received by 50% of PTV.[13] The ideal value of HI is 0. Lower values of HI indicate a more homogeneous dose distribution. As critical organs, lung-PTV (V_5,V_{10},V_{20}, and D_{mean}), heart (D_{mean} and V_{30}), liver (D_{mean}), bilateral kidney (D_{mean}, V_{12},V_{20},V_{23}, and V_{28}), and spinal cord (D_{max} and D_{1cc}) doses were evaluated. Furthermore, MU values were compared.

Statistical Analysis

Statistical analysis was performed in the SPSS (version 22.0) program. As the statistical comparison method, Wil-

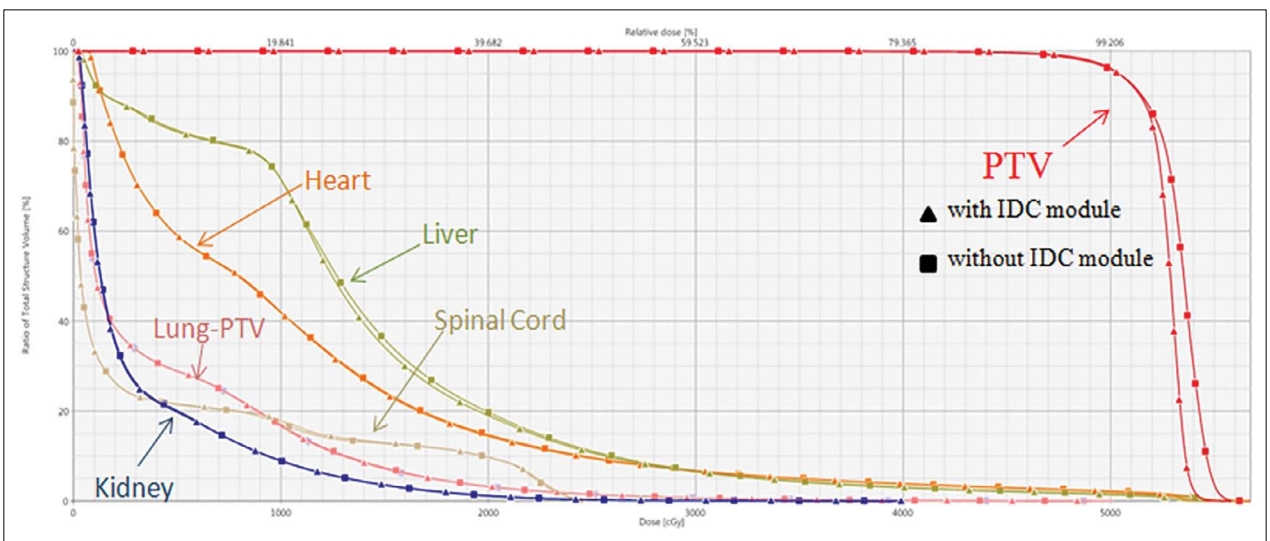

Fig. 1. The dose-volume histogram of volumetric modulated arc technique plans with and without intermediate dose calculation module for one abdominal esophagus patient.
PTV: Planning target volume; IDC: Intermediate dose calculation; Gy: Gray.

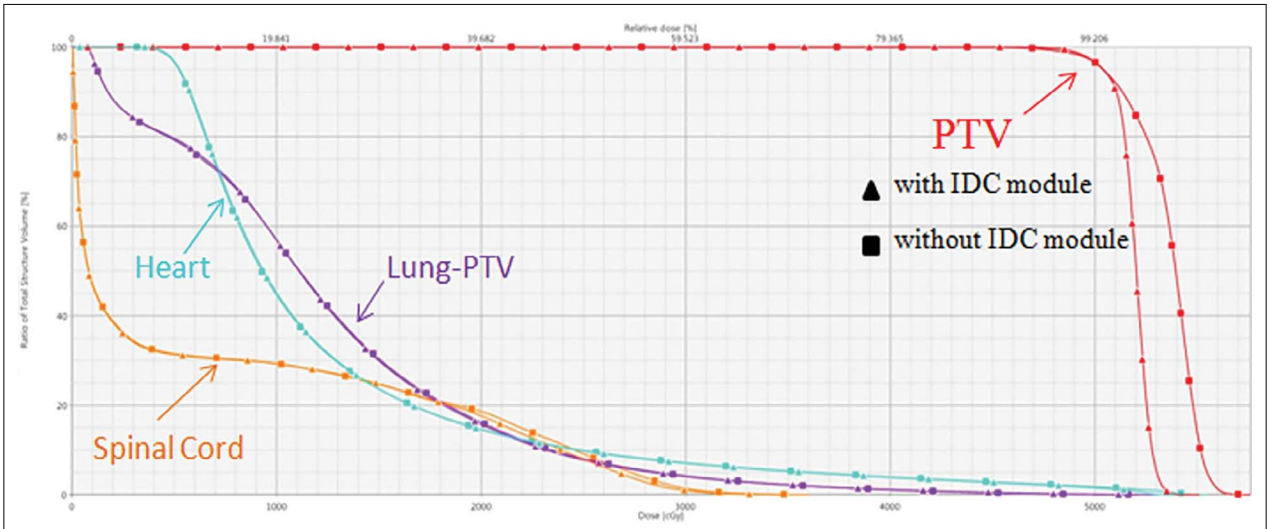

Fig. 2. The dose-volume histogram of volumetric modulated arc technique plans with and without intermediate dose calculation module for one thoracic esophagus patient.
PTV: Planning target volume; IDC: Intermediate dose calculation; Gy: Gray.

coxon-Signed Rank Test was used due to the small sample size. P<0.05 value was considered statistically significant.

Results

Evaluation of PTV and OARs Doses in Abdominal EC Patients

For abdominal EC patients, D_2, D_{98}, D_{mean}, CI, and HI values for PTVs in the plans created using AAA v15.6 with and without IDC module are given in Table 2. The MU values of the plans are also shown in Table 2. The lung-PTV (V_5,V_{10},V_{20}, and D_{mean}), heart (D_{mean} and V_{30}), liver (D_{mean}), bilateral kidney (D_{mean}, V_{12},V_{20},V_{23}, and V_{28}), and spinal cord (D_{max} and D_{1cc}) dose values in plans created using AAA v15.6 with and without IDC module for abdominal EC patients are given in Table 3.

Evaluation of PTV and OARs Doses in Thoracic EC Patients

For thoracic EC patients, D_2, D_{98}, D_{mean}, CI, and HI values for PTVs in the plans created using AAA v15.6 with and without IDC module are given in Table 4. The MU values of the plans are also shown in Table 4. The lung-PTV (V_5,V_{10},V_{20}, and D_{mean}), heart (D_{mean} and V_{30}), and spinal cord (D_{max} and D_{1cc}) dose values in plans created using AAA v15.6 with and without IDC module for thoracic EC patients are given in Table 5.

Discussion

Radiotherapy plays a predominant role within multimodal treatment concepts for ECs due to protecting esophageal shape and function.[16,17] In recent years,

Table 2 PTV doses of patients with abdominal esophageal cancer

	AAA without IDC	AAA with IDC	p* AAA without IDC versus AAA with IDC
D_{98}(cGy)	4884±28	4912±23	0.070
D_2 (cGy)	5433±67	5361±50	0.005
D_{mean} (cGy)	5274±49	5240±40.0	0.012
CI	1.184±0.037	1.170±0.036	0.008
HI	0.103±0.015	0.085±0.012	0.005
MU	426±45	415±44	0.005

p*: P<0.05 represents statistical significance. Data are presented as mean with SD. PTV: Planning target volume; AAA: Analytical anisotropic algorithm; IDC: Intermediate dose calculation; Gy: Gray; CI: Conformity index; HI: Homogeneity index; MU: Monitor unit

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Table 3 OARs doses of abdominal EC patients

OARs doses	AAA without IDC	AAA with IDC	p* AAA without IDC versus AAA with IDC
Lung-PTV V_5 (%)	40.3±12.4	40.1±12.4	0.031
Lung-PTV V_{10} (%)	27.0±10.5	27.0±10.3	0.074
Lung-PTV V_{20} (%)	7.5±4.0	7.5±4.0	0.414
Lung-PTV D_{mean} (cGy)	677±207	674±206	0.047
Heart D_{mean} (cGy)	1420±305	1415±304	0.203
Heart V_{30} (%)	9.7±2.9	9.7±2.9	0.317
Liver D_{mean} (cGy)	1810±416	1823±419	0.009
Bilateral kidney D_{mean} (cGy)	500±214	507±217	0.005
Bilateral kidney V_{12} (%)	10.4±8.0	10.6±8.2	0.057
Bilateral kidney V_{20} (%)	2.9±3.5	3.0±3.6	0.071
Bilateral kidney V_{23} (%)	2.0±2.8	2.1±2.8	0.023
Bilateral kidney V_{28} (%)	1.2±2.0	1.2±2.1	0.034
Spinal cord D_{max} (cGy)	3494±421	3518±438	0.285
Spinal cord D_{1cc} (cGy)	3257±394	3257±413	0.086

p*: P<0.05 represents statistical significance. Data are presented as mean with SD. OAR: Organs at risk; EC: Esophageal cancer; AAA: Analytical anisotropic algorithm; IDC: Intermediate dose calculation; PTV: Planning target volume; Gy: Gray

Table 4 PTV doses for thoracic esophagus patients

PTV doses	AAA without IDC	AAA with IDC	p* AAA without IDC versus AAA with IDC
D_{98}(cGy)	4905±24	4940±17	0.005
D_2 (cGy)	5587±75	5399±89	0.005
D_{mean} (cGy)	5373±49	5260±80	0.005
CI	1.256±0.042	1.233±0.038	0.009
HI	0.126±0.014	0.086±0.018	0.005
MU	415 ±59	398±55	0.005

p*: P<0.05 represents statistical significance. Data are presented as mean with SD. PTV: Planning target volume; AAA: Analytical anisotropic algorithm; IDC: Intermediate dose calculation; Gy: Gray; CI: Conformity index; HI: Homogeneity index; MU: Monitor unit

Table 5 OAR doses of thoracic esophagus patients

OAR doses	AAA without IDC	AAA with IDC	p* AAA without IDC versus AAA with IDC
Lung-PTV V_5 (%)	86.6±12.1	86.8±12.0	0.051
Lung-PTV V_{10} (%)	69.3±19.1	69.6±19.0	0.208
Lung-PTV V_{20} (%)	15.6±5.7	15.2±5.6	0.020
Lung-PTV D_{mean} (cGy)	1354±273	1353±272	0.475
Heart D_{mean} (cGy)	1623±424	1611±410	0.445
Heart V_{30} (%)	11.2±6.0	10.9±5.5	0.024
Spinal cord D_{max} (cGy)	3281±470.8	3200±507	0.013
Spinal cord D_{1cc} (cGy)	2971±470	2901±484	0.005

p*: P<0.05 represents statistical significance. Data are presented as mean with SD. OAR: Organs at risk; AAA: Analytical anisotropic algorithm; IDC: Intermediate dose calculation; PTV: Planning target volume; Gy: Gray

clinical studies have shown that IMRT and VMAT-based techniques are better than conventional 3-dimensional conformal radiation therapy with respect to improved PTV coverage and OARs sparing in the treatment of ECs.[18,19]

The treatment plans using IMRT and VMAT techniques are associated with a precise target volume and minimized side effects due to enhanced protection of the normal organ, but not always as desired. It requires the development of optimization algorithms used to reach an effective treatment plan in the optimization process. For this purpose, an intermediate dose option has been developed in the Eclipse TPS. In this study, it was aimed to investigate the effect of using the IDC module during the optimization of VMAT on plan quality for ten thoracic and ten abdominal EC patients.

When the data obtained at the end of the study were examined, CI and HI parameters were found to be significantly lower in treatment plans which optimized with IDC module for both abdominal and EC patients. In addition to these, D_2, D_{mean}, and MU parameters of PTVs also showed improvement. In addition to these, in the presence of IDC module, spinal cord D_{max} value was found to be 3200±507 cGy for thoracic esophagus patients. It was 3281±470.8 cGy in plans without IDC module.

Akbaş et al.[20] investigated the dosimetric impact of IDC on heterogeneous region radiotherapy planning. In their study, the treatment plans were created using AAA with and without IDC for 12 patients with maxillary sinus cancer patients. In this study, they reported that the HI and CI values were 0.090 and 1.142 and 0.067 and 1.055 for plans generated using AAA v15.1 without IDC and AAA v15.1 with IDC, respectively.

Kan et al.[21] reported that there was no difference according to the application of IDC in their phantom study. However, the authors used VMAT technique and evaluated the results according to application of an air cavity correction option simultaneously with the intermediate dose option. Li et al.[11] examined the effect of the IDC module on PTV and OAR using the IMRT technique for 11 lung cancer patients. They found that the HI and CI value of 0.12±0.04 and 0.59±0.11 and 0.08±0.03 and 0.69±0.10 for plans optimized with and without IDC module, respectively. In addition, D_{max} of the spinal cord was found to be 29.10±10.49 Gy and 31.39±9.71 Gy for plans optimized with and without IDC module, respectively. These results show positive parallelism with our study.

When the results of our study were evaluated, the use of the IDC module in the AAA algorithm improved HI and CI in the plans of patients with abdominal and thoracic EC patients. Some of the critical organ doses improved. In abdominal esophagus cancer irradiations, lung-PTV (V_5), lung-PTV (D_{mean}), liver (D_{mean}), kidney (D_{mean}), kidney (V_{23}), and kidney (V_{28}) doses are improved, while in thoracic esophagus cancer irradiations, lung-PTV (V_{20}), heart (V_{30}), spinal cord (D_{max}), and spinal cord (D_{1cc}) doses were reduced.

Conclusion

As a result of this study, it has been observed that the use of the IDC module during VMAT optimization for abdominal and thoracic esophagus cancer patients increased the quality of the plan and provided a slight improvement in critical organ doses.

Peer-review: Externally peer-reviewed.

Conflict of Interest: All authors declared no conflict of interest.

Ethics Committee Approval: The study was approved by the Istanbul University Istanbul Faculty of Medicine Ethics Committee (No: E-29624016-050.99-6125, Date: 06/01/2021).

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References

1. Kato H, Nakajima M. Treatments for esophageal cancer: a review. Gen Thorac Cardiovasc Surg 2013;61(6):330–5.
2. Shi HY, Liu ML, Zhu SC, Shen WB. Pathological characteristics of esophageal cancer. Oncology Letters 2014;8(2):533–8.
3. Kollarova H, Machova L, Horakova D, Janoutova G, Janout V. Epidemiology of esophageal cancer--an overview article. Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub 2007;151(1):17–20.
4. Yildirim M, Kaya V, Yildiz M, Demirpence O, Gunduz S, Dilli UD. Esophageal cancer, gastric cancer and the use of pesticides in the southwestern of Turkey. Asian Pac J Cancer Prev 2014;15(6):2821–3.

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doi: 10.5505/tjo.2022.3491

5. Ychou M, Boige V, Pignon JP, Conroy T, Bouché O, Lebreton G, et al. Perioperative chemotherapy compared with surgery alone for resectable gastroesophageal adenocarcinoma: an FNCLCC and FFCD multicenter phase III trial. J Clin Oncol 2011;29(13):1715–21.
6. Deng W, Lin SH. Advances in radiotherapy for esophageal cancer. Ann Transl Med 2018;6(4):79.
7. Allehyani SH, Sharyan HA, Tolba AR, Hassan RA. 3DCRT versus RapidArc in terms of Iso-dose distribution, Dose Volume Histogram (DVH) and organs at risk for esophageal cancer (EC) dosimetric study. AJCEM 2017;5(4):123–33.
8. Van Benthuysen L, Hales L, Podgorsak MB. Volumetric modulated arc therapy vs. IMRT for the treatment of distal esophageal cancer. Med Dosim 2011;36(4):404–9.
9. Kim YL, Chung JB, Kang SH. Dosimetric and radiobiological evaluation of dose volume optimizer (DVO) and progressive resolution optimizer (PRO) algorithm against photon optimizer on IMRT and VMAT plan for prostate cancer. Medical Physics 2018;29(4):106–14.
10. Klippel N, Schmücking M, Terribilini D, Geretschläger A, Aebersold DM, Manser P. Improved VMAT planning for head and neck tumors with an advanced optimization algorithm. Z Med Phys 2015;25(4):333–40.
11. Li Y, Rodrigues A, Li T, Yuan L, Yin FF, Wu QJ. Impact of dose calculation accuracy during optimization on lung IMRT plan quality. J Appl Clin Med Phys 2015;16(1):5137.
12. Park BD, Kim TG, Kim JE. Dosimetric impact of intermediate dose calculation for optimization convergence error. Oncotarget 2016;7(25):37589–98.
13. International Commission on Radiation Units and Measurements. Prescribing, recording, and reporting photon-beam intensity-modulated radiation therapy (IMRT). Journal of the ICRU 2010;10(1):Report 83.
14. Bentzen SM, Constine LS, Deasy JO, Eisbruch A, Jackson A, Marks LB, et al. Quantitative analyses of normal tissue effects in the clinic (QUANTEC): an introduction to the scientific issues. Int J Radiat Oncol Biol Phys 2010;76(3 Suppl):S3–9.
15. Paddick I. A simple scoring ratio to index the conformity of radiosurgical treatment plans. Technical note. J Neurosurg 2000;93 Suppl 3:219–22.
16. Nakamura JL, Verhey LJ, Smith V, Petti PL, Lamborn KR, Larson DA, et al. Dose conformity of gamma knife radiosurgery and risk factors for complications. Int J Radiat Oncol Biol Phys 2001;51(5):1313–9.
17. van Hagen P, Hulshof MC, van Lanschot JJ, Steyerberg EW, van Berge Henegouwen MI, Wijnhoven BP, et al; CROSS Group. Preoperative chemoradiotherapy for esophageal or junctional cancer. N Engl J Med 2012;366(22):2074–84.
18. Fenkell L, Kaminsky I, Breen S, Huang S, Van Prooijen M, Ringash J. Dosimetric comparison of IMRT vs. 3D conformal radiotherapy in the treatment of cancer of the cervical esophagus. Radiother Oncol 2008;89(3):287–91.
19. Ma P, Wang X, Xu Y, Dai J, Wang L. Applying the technique of volume-modulated arc radiotherapy to upper esophageal carcinoma. J Appl Clin Med Phys 2014;15(3):4732.
20. Akbas U, Koksal C, Kesen ND, Kaval G, Karaman S, Dağoğlu N, et al. Dosimetric impact of intermediate dose calculation on heterogeneous region radiotherapy planning. Physica Media 2018;52(suppl 1):99–187.
21. Kan MW, Leung LH, Yu PK. The performance of the progressive resolution optimizer (PRO) for RapidArc planning in targets with low-density media. J Appl Clin Med Phys 2013;14(6):4382.