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Comparison Of IMRT And Rapidarc Treatment Plans Using AAPM Task Group Test Suites

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Abstract

The purpose of this study is to examine the plan quality and monitor unit with sliding window IMRT and RapidArc (RA) treatment plans using American Association Physicists in Medicine TG119 test suite DICOM-RT images and structure sets. The structure set includes multi-target (superior, central, inferior), prostate, head and neck and C-shape. Plans were performed with Eclipse planning system using AAA algorithm with the plan goals specified in TG119. The plan results for multitarget shows that the D99 is greater than the plan goal for all the targets. The D10 is less than the plan goal for superior and inferior targets in both IMRT and RA plans. The D10 is 5% more with IMRT plan and 7% more with RA plan for central target in comparison with plan goal. The plan results for prostate shows that D95 is greater than the plan goal for both IMRT and RA plans. The D5 is less than the plan goal for IMRT plan and almost equal to plan goal for RA plan. The D30 is less than the plan goal for bladder and rectum in both the plans. The D10 is higher than the plan goal by 1.9% and 2.5% in IMRT and RA plan for rectum. The plan results for head and neck shows that the D99 and D90 were greater than the plan goal for PTV. The spinal cord and parotid doses were less than the plan goal in both the plans. The plan results for C-shape shows that the D95 was greater than the plan goal and D10 was less than the plan goal for PTV. The dose to central core was less than the plan goal in both IMRT and RA plans. Both the IMRT and RapidArc plans have met the plan goal for all the target and normal structures. RapidArc optimization and treatment planning requires more time than the IMRT plan. The monitor unit calculated by the RapidArc plan is less compared to IMRT plan, which reduces the treatment error caused by patient motion during treatment and integral dose

Keywords

IMRT, RapidArc, AAA, MLC, Treatment planning

Introduction

Intensity-modulated radiation therapy (IMRT) and intensity-modulated arc therapy (IMAT) are all advanced external beam radiation therapy treatment techniques that have been implemented for routine clinical use at different time points over the last 10 years(1). IMRT using a conventional linear accelerator equipped with a multi-leaf collimator (MLC) was adapted for clinical use to treat prostate cancer in 1995 (despite the fact that IMRT using compensators was performed earlier)(2). IMAT implemented with the gantry of the linear accelerator rotating during delivery along with MLC variations, was first proposed by Yu(3). The clinical implementation of IMAT was initially hampered because of optimization algorithm generated plans were difficult to deliver with conventional linear accelerator and MLC. Subsequently, the IMAT plans become deliverable by the linac system due to the incorporation of direct aperture optimization algorithm into planning system(4,5). Clinical arc therapy treatments were successfully tried for the treatment of central nervous system, prostate, head and neck, whole abdominopelvic treatments, rectal cancer and endometrial cancers(6,7,8). This IMAT approach involves several gantry rotations

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and thereby increases the treatment time. A major advance in IMAT was realized when Otto implemented his volumetric modulated arc therapy (VMAT) algorithm[8]. VMAT uses a progressive sampling algorithm which starts with coarse gantry samples and then, throughout the optimization, the arc resolution is gradually improved. Without this algorithm, neighboring segments are highly restricted by the allowed leaf motion. VMAT obviates this restriction by allowing large leaf movements early in the optimization and more restricted leaf motion in the later stages. The optimization time is also greatly reduced. Otto's algorithm has been implemented by Varian (Varian Medical Systems, Palo Alto, CA, USA) and is marketed as RapidArc. In this implementation, the progressive sampling is achieved through five discrete "multi-resolution" (MR) levels in which the number of segments increases from 10 to 177. Elekta (Elekta AB, Stockholm, Sweden) also have a product named VMAT, which uses a proprietary algorithm[9]. Both Varian's and Elekta's implementations of arc therapy allow for dose rate variations.

Oliver et al[10] characterize the difference in plan quality, planning time and delivery time for IMRT, arc therapy and Tomotherapy. Many studies have compared the IMRT with tomotherapy, IMRT with arc therapy, and tomotherapy with arc therapy. [7,11,12,13,14] There is a study that examines IMRT, arc therapy, and tomotherapy planning for five patients with benign intracranial lesions[15]. The study concludes that all techniques are practically equivalent in delivering homogenous dose to the target and sparing the normal structures. Furthermore, a publication by Bortfeld and Webb provided some theoretical considerations when considering the quality of dose distributions that can be achieved for IMRT, single arc IMRT, and tomotherapy based on a 2D phantom with an analytically derived solution[16]. They conclude that a single arc that is delivered in less than 2 minutes may unduly compromise the plan quality for very complex cases, and feel that the plan quality for IMRT and single arc VMAT are similar.

The purpose of this study is to create IMRT, RapidArc treatment plans for different shape structure sets with various organs at risk to be spared. The structure set includes multi-target, prostate, head and neck and C-shape. The treatment plan quality and monitor unit (MU) were analyzed for all the plans.

Material and Methods

In order to compare IMRT with Rapidarc plan results, we downloaded the American Association of Physicists in Medicine (AAPM) TG119 test suite DICOM-RT images and structure sets[17]. The treatment planning was carried out with Varian, Eclipse (Version 8.9.08) treatment planning system and the dosimetric comparison of the plans were made later.

Defining phantom, contour and plan objectives

The test suite consists of slab phantom CT images of dimension 30 cm x 30 cm x 15 cm with provision to place ionization chamber at 7.5 cm depth for point measurement. The planar dose measurements can also be carried out using an array detector or film on coronal planes. The present study describes only planning comparison between IMRT and RapidArc using TG119 test suites.

The simple field non-IMRT test plans were generated to demonstrate the reliability of the dosimetry and delivery systems. The test field includes simple uniform AP: PA fields and AP:PA fields with bands of varying doses. The later measurements were with four IMRT tests plans of doses rates varying between 180-200 cGy. The volume and location of the structures for the IMRT plans were downloaded as a DICOM-RT data from the AAPM central server and transferred to our scanned phantom. All tests were performed at 6 MV photon beam.

Simple AP: PA field

The simple parallel opposed fields were calculated using AP: PA technique of 10x10 cm2 fields to a dose of 200 cGy to the midpoint of the chamber (Figure 1).

AP: PA field with Bands

The parallel opposed field was calculated using

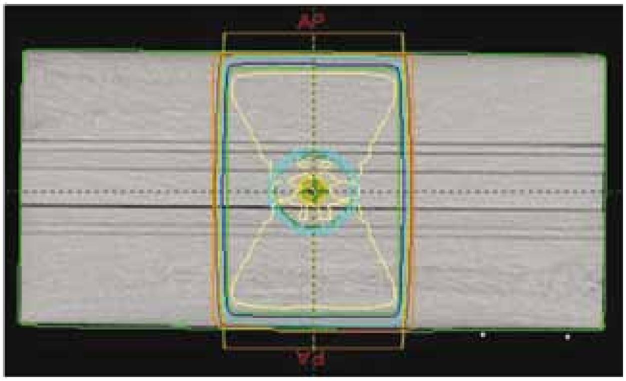

Fig. 1: Parallel opposed field irradiation AP:PA

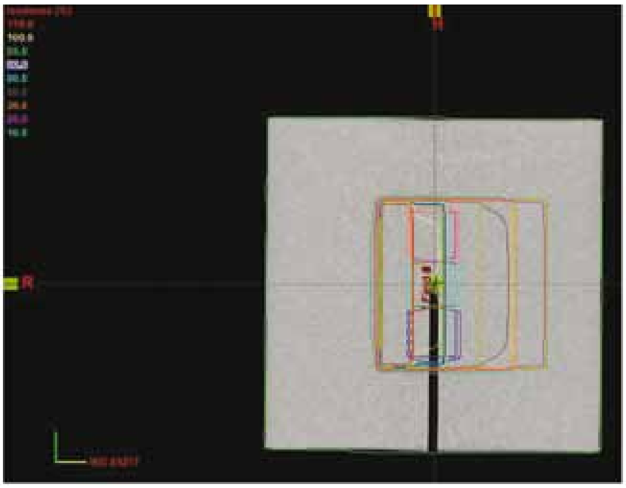

Fig. 2: Dose distribution for bands

series of AP: PA fields with a set of 5 bands, 3 cm wide receiving a dose from 40 to 200 cGy (Figure 2). The five opposed bands were created using asymmetric jaws with each band exposed for 40 cGy midpoint doses. These plans can be used to check the reliability of treatment planning system for non-IMRT fields.

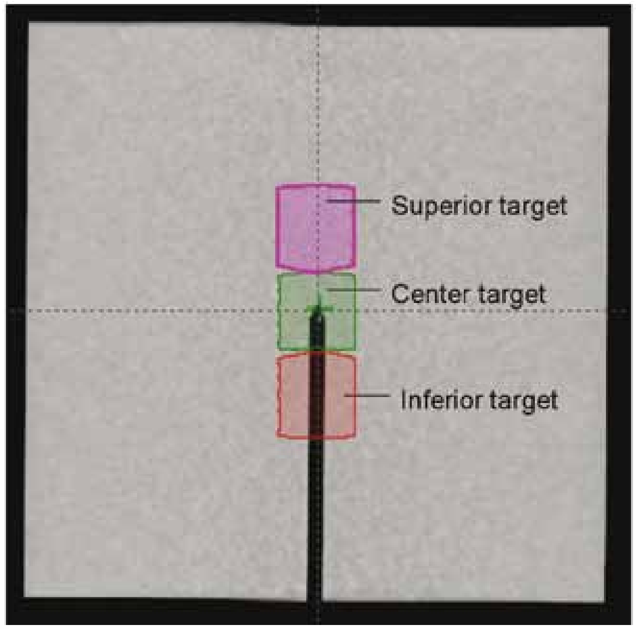

Fig. 3: Multitarget structures: Central target, superior target and inferior target

Multitarget

In the scanned phantom three cylindrical targets each having a length of 4 cm and diameter 4 cm are stacked along the axis of rotation (Figure 3). The central target was made to receive 100% of the planned dose per fraction. The superior and inferior target was planned to receive 50% and 25% of the central target dose. The dose goals used for planning were expressed in terms of dose to 99% of the volume (D99) and dose to 10% of the volume (D10) for the targets. The plan constraints for different targets are specified in (Table 1).

Plan goal		
Structure	Dose (cGy)	
Central target	$D_{99} > 5000$	$D_{10} < 5300$
Superior target	$D_{99} > 2500$	$D_{10} < 3500$
Inferior target	$D_{99} > 1250$	$D_{10} < 2500$
IMRT plan result		
Structure	Dose (cGy)	
Central target	D_{99} = 5004 cGy	D_{10} = 5551 cGy
Superior target	D_{99} = 2760 cGy	D_{10} = 3065 cGy
Inferior target	D_{99} = 1357 cGy	D_{10} = 1677 cGy
RapidArc plan result		
Structure	Dose (cGy)	
Central target	D_{99} = 5082 cGy	D_{10} = 5655 cGy
Superior target	D_{99} = 2693 cGy	D_{10} = 3093 cGy
Inferior target	D_{99} = 1294 cGy	D_{10} = 1691 cGy

Table 1 : Treatment plan statistics for multitarget

Prostate

The tested elliptical and posterior concave prostate clinical target volume (CTV) had right-left lateral (RL), anterior-posterior (AP) and superior-inferior (SI) dimensions of 4.0, 2.6 and 6.5 cm respectively. The prostate planning target volume (PTV) is expanded 0.6 cm around the CTV. The rectum assumed to be a cylinder of 1.5 cm diameter that abuts the indented posterior aspects of the prostate. The marked PTV included about 1/3 of the rectal volume on the widest PTV slice. The bladder is ellipsoidal with RL, AP and SI dimensions of 5.0, 4.0 and 5.0 cm respectively and is centered on the superior aspects of the prostate (Figure 4). For the prostate PTV the dose goal was specified as D95 and D5. For bladder and rectum D30 and D10 were used. (Table 2) shows the dose constraints for the plan.

Head and neck

The head neck PTV includes all anterior volume from the base of the skull to the upper neck, including posterior neck nodes. The PTV is retracted from the skin by 0.6 cm. There is a gap of about 1.5 cm between the cord and the PTV. The parotid glands are to be avoided and are the superior aspects of the PTV (Figure 5). For head and neck PTV the dose goal was specified as D99, D90 and D20. For normal structures, D50 was used for parotid and maximum dose for spinal cord. (Table 3) includes the specific plan goals.

C-shape

The target is a C-shape that surrounds a central avoidance structure. The central core is a cylinder of 1 cm radius. The gap between the core and the PTV is 0.5 cm, so the inner arc of the PTV is 1.5 cm in radius. The outer arc of the PTV is 3.7 cm in radius. The PTV is 8 cm long and the core is 10 cm long (Figure 6). For C-shape PTV the dose goal was specified as D95, D10. For core

Plan goal		
Structure	Dose (cGy)	
Prostate PTV	D_{95}> 7560	D_5< 8300
Rectum	D_{30}< 7000	D_{10}< 7500
Bladder	D_{30}< 7000	D_{10}< 7500
IMRT plan result		
Structure	Dose (cGy)	
Prostate PTV	D_{95} = 7599 cGy	D_5 = 8120 cGy
Rectum	D_{30} = 6460 cGy	D_{10} = 7644 cGy
Bladder	D_{30} = 3853 cGy	D_{10} = 6080 cGy
RapidArc plan result		
Structure	Dose (cGy)	
Prostate PTV	D_{95} = 7688 cGy	D_5 = 8352 cGy
Rectum	D_{30} = 6345 cGy	D_{10} = 7688 cGy
Bladder	D_{30} = 4433 cGy	D_{10} = 6354 cGy

Table 2 : Treatment plan statistics for prostate

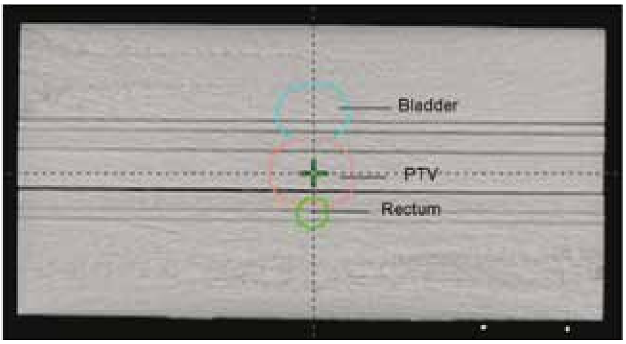

Fig. 4: Prostate structures: PTV, bladder and rectum

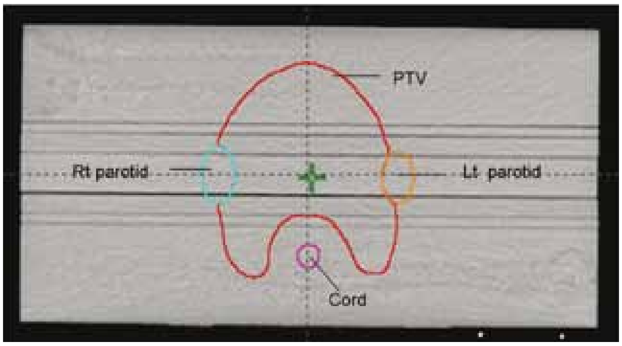

Fig. 5: Head and neck structures: HN PTV, cord and parotid glands

Plan goal		
Structure	Dose (cGy)	
H&N PTV	D_{90}> 5000	D_{99}> 4650
	D_{20}< 5500	
Cord	Max dose = 4000	
Parotids	D_{50}< 2000	
IMRT plan result		
Structure	Dose (cGy)	
H&N PTV	D_{90} = 5035 cGy	D_{99} = 4868 cGy
	D_{20} = 5225 cGy	
Cord	Max. Dose = 3312 cGy	
Parotids	D_{50} = 1725 cGy (Lt)	
	D_{50} = 1693 cGy (Rt)	
RapidArc plan result		
Structure	Dose (cGy)	
H&N PTV	D_{90} = 5038 cGy	D_{99} = 4826 cGy
	D_{20} = 5359 cGy	
Cord	Max. Dose = 3327 cGy	
Parotids	D_{50} = 1766 cGy (Lt)	
	D_{50} = 1615 cGy (Rt)	

Table 3 : Treatment plan statistics for Head & Neck

Plan goal		
Structure	Dose (cGy)	
C-shape PTV	D_{95}> 5000	D_{10}<5500
Core	D_5<2500	
IMRT plan result		
Structure	Dose (cGy)	
C-shape PTV	D_{95} = 5017 cGy	D_{10} = 5374 cGy
Core	D_5 = 1656 cGy	
RapidArc plan result		
Structure	Dose (cGy)	
C-shape PTV	D_{95} = 5012 cGy	D_{10} = 5441 cGy
Core	D_5 = 1907 cGy	

Table 4 : Treatment plan statistics for C-shape

normal structures, D10 was used. The plan goals are shown in (Table 4).

Sliding window IMRT planning

The sliding window IMRT planning was performed with Eclipse planning system (Eclipse version 8.9.08) using Dose Volume Optimizer (DVO). The Anisotropic Analytical Algorithm (AAA) was used with the calculation grid of 2.5 mm. The 6 MV photons from the Novalis Tx linear accelerator was used with the dose rate of 600 cGy/min. The multi-target and prostate plans were executed with seven 6 MV photon beams placed at 500 intervals from the vertical beam (0°, 50°, 100°, 150°, 310°, 260°, 210°). The head and neck and C-shape plans were executed with nine 6 MV photon beams placed at 400 intervals from the vertical beam (0°, 40°, 80°, 120°, 160°, 200°, 240°, 280°, 320°).

RapidArc (RA) planning

RapidArc is also known as volumetric modulated arc therapy (VMAT), requires single gantry rotation and produces the conformal dose distribution. The VMAT can deliver radiation dose from 360°, it offers more conformal dose relative to IMRT using limited number of fields and gantry rotation. The RapidArc planning

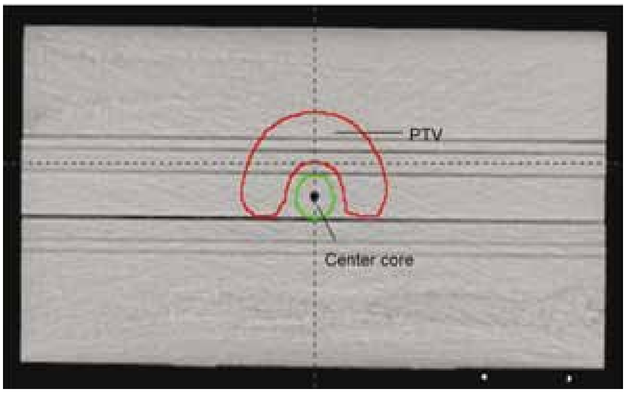

Fig. 6: C-shape structures: C-shape PTV and core

algorithm is based on the direct MLC leaf optimization method described by Otto et al[9]. Both MLC position and monitor unit (MU) are included as optimization parameters, with a cost function based on dose-volume constrains of the target and normal tissues. During optimization, further constrains are imposed on MLC motion, dose-rate and gantry speed. The optimization process begins with a small number of control points, gradually increasing them to a sufficient number to ensure dose calculation accuracy. The treatment planning system creates ≤177 control points, each control point identifies the MLC position, dose rate and gantry speed.

In RapidArc mode, Eclipse optimizes machine parameter directly, there is no fluence pattern and leaf motion calculation is performed by the system. The transition fluence is calculated from optimized machine parameters for each control point. Optimization is completed in one step before the dose calculation. RapidArc optimization deals with resolution levels, or number of control points. The optimized leaf position and MU/degree values are defined at each control point. In the optimization process, the critical structures are shielded first, and target converges are optimized at the end. The AAA algorithm calculates the dose distribution for each control point. After calculation the control points are used for treatment delivery. All the test plans were created with single arc and gantry rotation 180.1° and gantry stop angle 179.9° towards the clockwise direction. The collimator was rotated to 45° to avoid tongue-groove effect.

Results and Discussion

The treatment plan goal and results for multi-target IMRT and RapidArc plans are shown in Table 1. The dose to 99% of volume (D99) and dose to 10% of volume (D10) were considered for central target, superior and inferior target structures. The plan result shows that the D99 is greater than the plan goal for all the targets. The D10 is less than the plan goal for superior and inferior targets in both IMRT and RA plans. The D10 is 5% more with IMRT plan and 7% more with RA plan for central target in comparison with plan goal. The treatment plan goal and results for prostate IMRT and RapidArc plans are shown in (Table 2). The dose to 95% of volume (D95) and dose to 5% of volume (D5) were considered for prostate PTV and dose to 30% of volume (D30) and dose to 10% of volume (D10) were considered for rectum and bladder. The plan result shows that D95 is greater than the plan goal for both IMRT and RA plans. The D5 is less than the plan goal for IMRT plan and almost equal to plan goal for RA plan. The D30 is less than the plan goal for bladder and rectum in IMRT and RA plans. The D10 is higher than the plan goal by 1.9% and 2.5% in IMRT and RA plan for rectum.

The treatment plan goal and the results for head and neck IMRT and RapidArc plans are shown in Table 3. The dose to 99% of volume (D99) and dose to 90% of volume (D90) were considered for PTV. The maximum dose was considered for spinal cord and D50 was considered for parotid. The plan result shows that the D99 and D90 were greater than the plan goal for PTV. The spinal cord and parotid doses were less than the plan goal in both IMRT and RA plans. The treatment plan goal and the results for C-shape IMRT and RapidArc plans are shown in Table 4. The dose to 95% of volume (D95) and dose to 10% of volume (D10) were considered for PTV. The dose to 5% of volume (D5) was taken for central core. The plan result shows that the D95 was greater than the plan goal and D10 was less than the plan goal for PTV. The dose to central core was less than the plan goal in both IMRT and RA plans.

For the multitarget, the calculated monitor unit (MU) was 848 and 622 for IMRT and RA plans. For the prostate, the calculated MU was 605 and 506 for IMRT and RA plans respectively. For the head & neck, the calculated MU was 1485 and 713 for IMRT and RA plans respectively. For C-shape, the calculated MU was 1402 and 745 for IMRT and RA plans respectively. The result shows that RA plans gives less MU than the IMRT plans. The MU is more significant, when large numbers of fields are used in the IMRT plan. Though, the treatment planning time is more in RA, which reduces the treatment delivery time by reducing the number of monitor units.

Conclusion

Advanced radiation therapy delivery techniques have their own relative merits. The results show that degree of target coverage and organ at risk (OAR) or healthy tissue sparing by the RapidArc plan is comparable to that of the IMRT plan. The RapidArc optimization and treatment planning requires more time compared to IMRT treatment planning. The treatment delivery time per fraction with RapidArc is less, which might reduce the probability of treatment error caused by patient motion during treatment.

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