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PHYSICS CONTRIBUTION

COMMISSIONING AND QUALITY ASSURANCE OF RAPIDARC RADIOTHERAPY DELIVERY SYSTEM

C. Clifton Ling, Ph.D.,*† Pengpeng Zhang, Ph.D.,† Yves Archambault, M.Sc.,* Jiri Bocanek, M.Sc.,* Grace Tang, M.Phil.,‡ and Thomas LoSasso, Ph.D.†

*Varian Medical Systems, Palo Alto, CA; †Memorial Sloan-Kettering Cancer Center, New York, NY; and ‡University of Maryland, Baltimore, MD

Purpose: The Varian RapidArc is a system for intensity-modulated radiotherapy (IMRT) treatment planning and delivery. RapidArc incorporates capabilities such as variable dose-rate, variable gantry speed, and accurate and fast dynamic multileaf collimators (DMLC), to optimize dose conformality, delivery efficiency, accuracy and reliability. We developed RapidArc system commissioning and quality assurance (QA) procedures.

Methods and Materials: Tests have been designed that evaluate RapidArc performance in a stepwise manner. First, the accuracy of DMLC position during gantry rotation is examined. Second, the ability to vary and control the dose-rate and gantry speed is evaluated. Third, the combined use of variable DMLC speed and dose-rate is studied.

Results: Adapting the picket fence test for RapidArc, we compared the patterns obtained with stationary gantry and in RapidArc mode, and showed that the effect of gantry rotation on leaf accuracy was minimal ($\leq$0.2 mm). We then combine different dose-rates (111–600 MU/min), gantry speeds (5.5–4.3°/s), and gantry range ($\Delta\theta$ = 90–12.9°) to give the same dose to seven parts of a film. When normalized to a corresponding open field (to account for flatness and asymmetry), the dose of the seven portions show good agreement, with a mean deviation of 0.7%. In assessing DMLC speed (0.46, 0.92, 1.84, and 2.76 cm/s) during RapidArc, the analysis of designed radiation pattern indicates good agreement, with a mean deviation of 0.4%.

Conclusions: The results of these tests provide strong evidence that DMLC movement, variable dose-rates and gantry speeds can be precisely controlled during RapidArc.

RapidArc, Commissioning, QA.

INTRODUCTION

Intensity-modulated radiotherapy (IMRT) has been established as accurate, reliable, and efficient in delivering conformal radiotherapy (1, 2). By maximizing tumor dose while sparing normal tissues, IMRT can improve the efficacy of radiotherapy. Delivery of IMRT is possible using different methods: for example, in slice-by-slice rotational therapy using binary collimation (3, 4), or computer-controlled multileaf collimators (MLC) in static (SMLC for segmental MLC) or dynamic (DMLC or sliding window) mode (1, 5).

Another IMRT method was proposed by Yu, combining gantry rotation and aperture changes for intensity-modulated arc therapy (IMAT) (6). Clinical implementation of IMAT was initially hampered because the optimization algorithm generated plans difficult to deliver with conventional linear accelerators (linacs) and MLCs. Subsequent research led to direct aperture optimization, that takes into account the constraints of varying the aperture shape with SMLC (7–9). That development led researchers to evaluate the potential of applying direct aperture optimization to IMAT optimization, constraining the plans to be deliverable by the linac systems (10, 11). One IMAT approach involves several gantry rotations and thereby increases treatment time. Another approach, proposed by Otto as volumetric modulated arc therapy (VMAT), requires only one gantry rotation and produces dose distributions equivalent to or better than those of IMRT (12).

The IMAT or VMAT approach has a number of potential advantages (6, 12). In being able to deliver radiation from 360°, it may offer more conformal dose distributions relative to IMRT using only a limited number of fields and gantry directions. Plan optimization becomes simpler, as it obviates questions of beam number and direction. Compared with tomotherapy, the use of a cone beam improves delivery efficiency significantly. Specifically, by using a volumetric irradiation volume, VMAT is five to 15 times more efficient, in terms of treatment time and monitor units, than the slice-by-slice tomotherapy (12). Another important factor is that

Reprint requests to: C. Clifton Ling, 1275 York Avenue, New York, NY 10021. Tel: (212) 639-8301; Fax: (212) 717-3010; E-mail: lingc@mskcc.org

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it can be implemented with a general-purpose linac for maximum clinical flexibility.

Many publications have documented that highly conformal dose distributions can be achieved with IMAT or VMAT (6, 10, 12). A recent publication directly compared the dose distributions achievable with IMAT and tomotherapy (13). The overall conclusions are that IMAT dose distributions are highly conformal and are equal to or superior to those generated by tomotherapy in the majority of cases (13).

Recently, the Varian RapidArc has become available for the treatment planning and delivery of arc-dynamic IMRT. The RapidArc planning algorithm is based on the direct MLC leaf position optimization method described by Otto (12). Briefly, both MLC position and monitor unit (MU) are included as optimization parameters, with a cost function based on dose–volume constraints of the target and normal tissues. During optimization, further constraints are imposed on MLC motion, dose-rate, and gantry speed such that these are within the capabilities of the Clinac. The optimization process begins with a small number of control points, gradually increasing them to a sufficient number to ensure dose calculation accuracy. As implemented in the initial release of the Eclipse planning system, $\leq$177 control points are used for each RapidArc treatment.

To maximize the benefits of the RapidArc approach, both the treatment planning and linac systems incorporate the following capabilities: variable dose-rate, variable gantry speed, and DMLC movement, with the expectation that these will optimize dose conformality, delivery efficiency, accuracy, and reliability. Thus, although RapidArc is an extension of the IMRT-DMLC concept, the delivery of RapidArc requires added functionality. Over the last year, testing of the various components of RapidArc has provided proof-of-principle demonstration of the potentials of this approach (14, 15). Recently, extensive and systematic evaluation of both RapidArc planning and delivery has been conducted at several institutions and will be reported in upcoming meetings (private communications from Stine Korenman, Luca Cozzi, PengPeng Zhang, Wilko Verbakel, and others).

The advanced technologies required for RapidArc delivery, i.e. variable dose-rate, variable gantry speed, rapid and bi-directional MLC movement within a single arc treatment field, are only now becoming available. Methods for system commissioning and for routine quality assurance (QA) have not been previously reported. The purpose of this study is to design and test such commissioning and QA protocols in advance of clinical implementation of RapidArc. As of May 9, 2008, RapidArc treatment has been clinically implemented in three institutions in the United States and Europe. Before that, the protocols described in this paper were tested and validated using both film and electronic portal imaging device (EPID) dosimetry systems.

METHODS AND MATERIALS

As RapidArc is only beginning to be implemented, practical experience is lacking. Thus, at present the commissioning and routine QA procedures cannot be clearly separated, but will evolve and mature with the accumulation of experience and physics data (16–18). That said, it is of immediate importance that programs be developed, and tests designed that assay the critical elements of RapidArc.

Prerequisites for RapidArc QA

RapidArc is an extension of IMRT-DMLC, and institutions that will implement RapidArc should be familiar with IMRT-DMLC commissioning and QA (17–21). Also, standard machine QA and IMRT-DMLC QA are prerequisites for RapidArc QA: for example, gantry and MLC iso-centricity, gantry position indicators, and dose calibration in both static gantry and arc therapy mode. We also assume picket fence tests at multiple gantry angles, and dose measurement for a 4 $\times$ 10-cm field with a 0.5-cm DMLC slit at different gantry angles to assess the effect of gravity on the MLC carriage (20).

Approach to RapidArc Commissioning and QA

The RapidArc commissioning and QA program will test and ensure reliable system capabilities that are incremental to those of IMRT-DMLC. The three most important elements are accuracy in DMLC position and precise dose-rate control during gantry rotation, and accurate control of gantry speed. In RapidArc delivery, the Clinac executes processes that implement the appropriate gantry speed, dose-rate and MLC motion so as to comply with the parameters specified in the RapidArc treatment plan. Thus one needs to assess the performance of the machine in all these areas.

Our approach is a series of tests that evaluate the machine performance in a stepwise manner. First, we shall examine the accuracy of MLC position; second, the control of dose-rate and gantry speed; and third, the combined use of dynamic MLC and variable dose-rate to achieve a certain dose pattern.

RapidArc-enabled Clinac

For subsequent discussion we define the following (12):

- θ = gantry angle
- $\Delta\theta/\Delta t$ = gantry speed
  $(\Delta\theta/\Delta t)_r$ = reference gantry speed of 360°/65 s, or 5.54°/s
  The gantry can rotate faster, but $(\Delta\theta/\Delta t)_r$ is a constraint used in Eclipse
- x = position of an MLC leaf
- $\Delta x/\Delta t$ = leaf speed
  $(\Delta x/\Delta t)_{max}$ = 2.76 cm/s; $(\Delta x/\Delta\theta)_{max}$ = 5.0 mm/° at $(\Delta\theta/\Delta t)_r$
- MU = dose in monitor units
- $\Delta MU/\Delta t$ = doserate
  The maximum, $(\Delta MU/\Delta t)_{max}$, is 600 MU/min
- $\Delta MU/\Delta\theta$ = (doserate/gantry speed); 1.8 MU/° at $(\Delta MU/\Delta t)_{max}$ and $(\Delta\theta/\Delta t)_r$
  The minimum, $(\Delta MU/\Delta t)_{min}$, is 0.1 MU/°

The tests were performed on a RapidArc-enabled Varian Trilogy linac, using 6 MV X-ray. A RapidArc plan is constructed as a sequence of control points, for each of which the gantry angle, cumulative fractional MU and MLC positions are specified. When loaded on the machine, the plan is decomposed into two groups of control parameters. The MLC positions as a function of gantry angle are sent to the MLC controller. The gantry angle as a function of cumulative MU is sent as a segmented treatment table (22) to the Clinac control system, which translates the segmented treatment table into commands that controls the dose-rate and gantry speed during RapidArc. Dose-rate modulation is achieved by timing of the

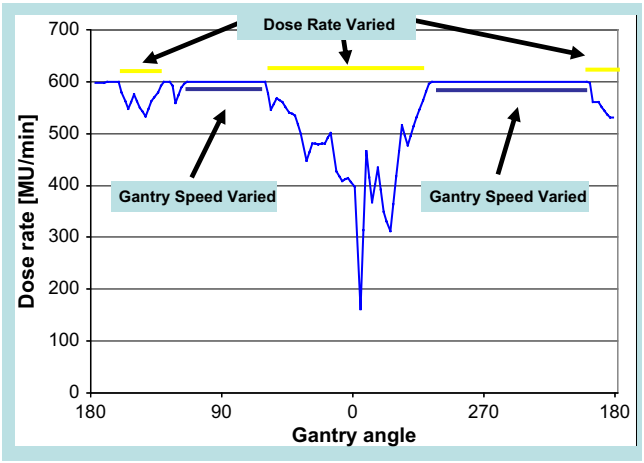

Fig. 1. Method for variation of $\Delta MU/\Delta\theta$ during RapidArc delivery.

microwave pulse and electron injection (from the gridded gun) into the accelerator guide, which when in coincidence result in an X-ray pulse. By delaying the electron pulse relative to the microwave pulse, the X-ray pulse is suppressed, hence lowering the effective dose-rate. Once initiated, the dose-rate can, in 10 ms go from the maximum to zero, or in the reverse, with variations in steps of 1.67 MU/min from the maximum of 600 MU/min. A diagram illustrating the method for the variation of $\Delta MU/\Delta\theta$ during RapidArc delivery is shown in Fig. 1.

Dosimetric equipment

Whereas film is used in this study, the proposed tests can also be performed with other dosimetric media (*e.g.,* radiochromic film, or an EPID device), with the requirement that the recording system rotate with the gantry. In this study we used radiographic film (Kodak XV) that was affixed to the isocentric mounting fixture (IMF)–MapCheck[1] device at 98.7 cm source to surface distance, or on the blocking tray (65.4-cm source to film distance), without build-up. (Subsequently the procedures have been tested and validated using electronic portal imaging device.)

To assess the mechanical stability of the IMF, a piece of film was affixed to it, and repeatedly exposed with a slit x-ray field of different lengths (delimited by the jaws) at θ of 0°, 90° and 270°.

Test 1: Accuracy of DMLC position during RapidArc

To assess the accuracy of DMLC leaf positions, we designed RapidArc plans of picket fence patterns, for comparison with the same pattern acquired with static gantry (16). Several tests were performed. First, individual picket fence patterns were acquired at stationary gantry angle of 0° and in RapidArc mode, with collimator angles of 0° and 45°. Second, films were exposed twice, at a 0° gantry angle with a field length of 12 cm delimited by the jaws and then in RapidArc mode with a 25-cm field length. Third, intentional changes in positions and widths of the picket-fence were introduced to assess the sensitivity of the test.

Test 2: Ability to vary dose-rate and gantry speed during RapidArc

In this test we evaluated the ability of the Clinac to modulate dose-rate and gantry speed to achieve the specified values. We affixed a film onto the IMF and irradiated different parts of the film to the same MU but with different combinations of $\Delta MU/\Delta t$, $\Delta\theta$ and $\Delta\theta/\Delta t$. Seven static MLC fields of 20 × 1.8 cm were spaced 2 cm apart (center to center), and irradiated during gantry rotation (denoted as the 7sQA plan). The 7sQA used the following combinations of $\Delta MU/\Delta t$ and $\Delta\theta$ (at $(\Delta\theta/\Delta t)_r$, unless otherwise specified): 111 MU/min for 90°, 222 MU/min for 45°, 332 MU/min for 30°, 443 MU/min for 22.5°, 554 MU/min for 18°, 600 MU/min for 15° (at reduced $\Delta\theta/\Delta t$ of 5°/s), and 600 MU/min for 12.9° (at reduced $\Delta\theta/\Delta t$ of 4.3°/s). In terms of $\Delta MU/\Delta\theta$ these are equivalent to 0.33, 0.67, 1.0, 1.33, 1.67, 2 and 2.33 MU/°. To achieve 2 and 2.33 MU/°, $(\Delta MU/\Delta t)_{max}$ would be exceeded at $(\Delta\theta/\Delta t)_r$, but the specified $\Delta MU/\Delta\theta$ can be achieved with reduction in $\Delta\theta/\Delta t$ to 5 at 4.3°/s. These $\Delta MU/\Delta\theta$ values would correspond to $\Delta MU/\Delta t$ of 665 and 773 MU/min at $(\Delta\theta/\Delta t)_{r\ r}$.

Test 3: Ability to accurately vary MLC leaf speed during RapidArc

Having validated MLC accuracy and the Clinac's ability to vary dose-rate and gantry speed in the previous tests, we evaluated the MLC leaf-speed control during RapidArc. Different parts of a film were exposed to the same dose using DMLC sliding window technique, combining different leaf speeds with different dose-rates to achieve a designed dose pattern (denoted as the leaf speed quality assurance [LSQA] plan). Specifically, we used the following combination of MLC leaf speeds and dose-rates: 0.46 cm/s and 138 MU/min, 0.92 cm/s and 277 MU/min, 1.84 cm/s and 554 MU/min, and 2.76 cm/s and 554 MU/min. The width of DMLC fields was 4.5 cm for the last leaf-speed/dose-rate combination, and 3 cm for the others.

Generation of RapidArc plan

To generate a RapidArc QA plan, the desired MLC, gantry angle, and fractional dose at each control points were compiled using the MatLab program (Mathworks, Natick, MA), the output of which is converted to the standard digital imaging and communications in medicine for radiation therapy format using a program from Memorial Sloan-Kettering Cancer Center. Finally, the digital imaging and communications in medicine for radiation therapy plan was imported into a RapidArc-Eclipse platform, which produced a RapidArc plan.

Normalization of the RapidArc measurement to open fields

To account for the influence of field flatness and asymmetry, we performed open field measurement for the same overall field size at 0° gantry angle. The data measured for RapidArc were then normalized to the open field.

Record of machine performance during RapidArc

Machine performance during RapidArc was recorded in two Dynalogs files. The Clinac control system captures MU and gantry angle every ~50 ms, and its Dynalog report gives comparison of planned θ and cumulative MU vs. the recorded values. The second Dynalog (from the MLC control computer) recorded MLC positions and θ every ~50 ms.

RESULTS

Accuracy of DMLC position during RapidArc

A film, mounted on the IMF and repeatedly exposed to a slit radiation field (defined by the MLC) of different lengths (defined by the upper jaws), is shown in Fig. 2a. The top and bottom sections were singly exposed at $\theta = 0°$. Relative to the top and bottom sections, the in-between sections (double

[1] The Sun Nuclear IMF) is directly mounted on the gantry, and the MapCheck matrix detectors in turn on the IMF, at 100 cm SAD.

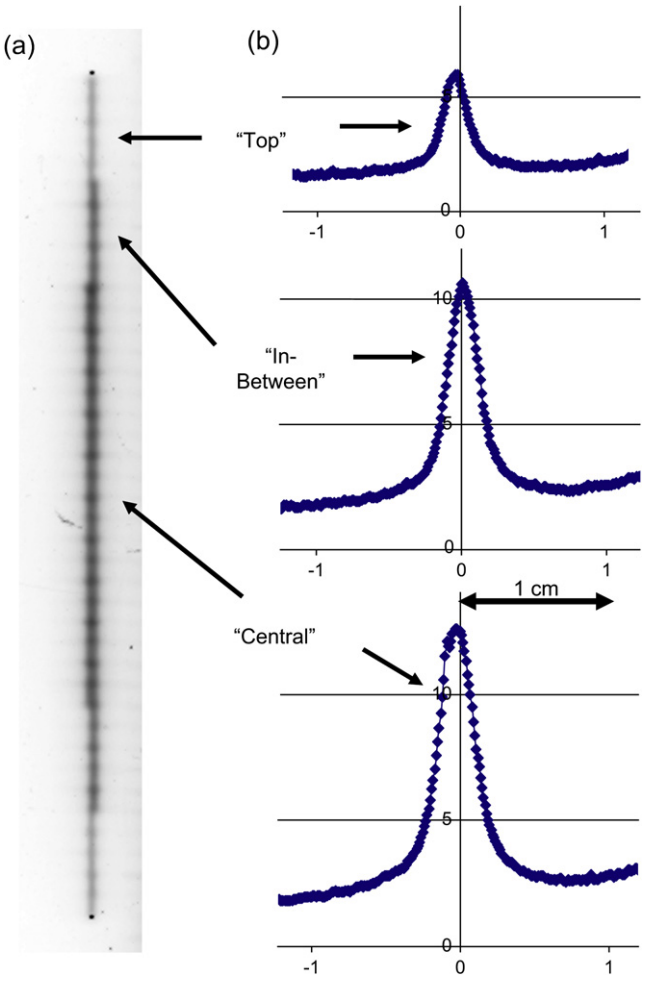

Fig. 2. (a) Image of a film mounted on the isocentric mounting fixture (IMF) and repeatedly exposed to a slit radiation field. (b) Radiation profiles of the image.

exposure at θ of 0° and 90°) show a broader image, indicative of a change in the position of the slit field on the film. The central region, exposed three times at θ of 0°, 90°, and 270°, shows an even broader image but with the shift going in the other direction relative to that of in-between sections. The profiles of the X-ray field(s) at different longitudinal positions, as produced by a film scanner, are shown in Fig. 2b. The first profile, with a full-width at half-maximum (FWHM) of ~2.2 mm, is that of the top section and has the lowest signal because it was irradiated only once. The second panel, representing the profile of the in-between section, is broader and shifted to the right (FWHM of ~2.6 mm). The third panel is the profile of the central region and shows additional broadening and a shift to the left relative to the second panel (FWHM of ~2.9 mm). These results are consistent with a slight sagging of the IMF as it becomes cantilevered during gantry rotation. The amount of the shifts, as quantified by linear measurement on the profile scans in Fig. 2b are approximately 0.3 mm, was judged acceptable for the use of the IMF in RapidArc QA.

With films attached to either the IMF or the block tray, the picket fence patterns were acquired at stationary gantry (θ = 0°) and during RapidArc delivery with gantry rotation of 110° and 360°. The resulting picket fence patterns were very similar, and side-by-side visual comparison was not helpful in discerning any difference between them. Analysis with a film scanner indicated that the widths of the picket fences were no different within measurement error of 0.2 mm. These tests showed that the uncertainty in DMLC position during RapidArc is minimal.

Figure 3 shows a film that was exposed twice to the 1-mm-wide picket fence pattern, once at θ = 0° (field length of 12 cm) and a second time in RapidArc mode (25-cm field length). Visual inspection indicates that the two picket fence patterns are well-aligned. Analysis with a film scanner indicated that the double-exposed picket fences were slightly broader (with FWHM increasing from 1.0 to 1.1 mm) and their centers slightly shifted by ≤0.2 mm.

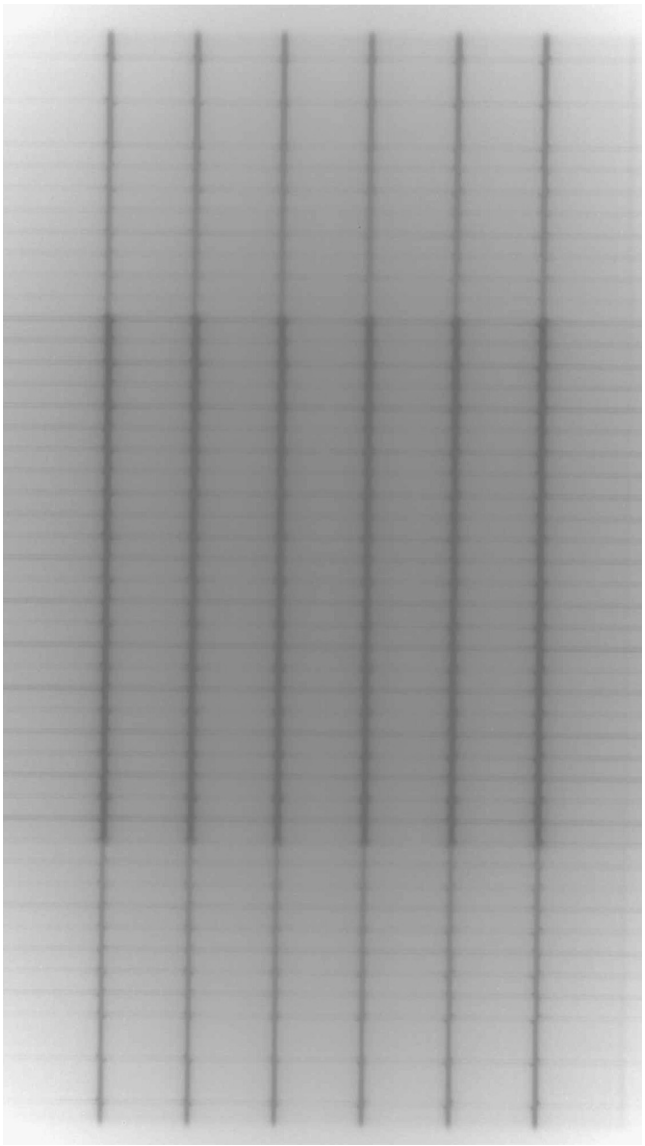

Fig. 3. Image of a film that was exposed twice to the 1-mm-wide picket fence pattern, once at stationary gantry angle and a second time in RapidArc mode.

Figure 4 shows a film exposed to the RapidArc picket fence plan with the ''intentional'' errors in position (0.5 mm) and width (1.5 mm instead of 1 mm). The 1.5-mm-wide fence (marked by a bar) and the ''shifted'' fence (marked by an arrow) were easily visualized on the exposed film. The picket fence pattern was also acquired with a 45° collimator rotation, yielding the same results.

Variable dose-rate and gantry speed during RapidArc

Figure 5 shows a film mounted on the IMF and exposed to the 7sQA plan, which delivered the same dose to the seven strips with different combinations of $\Delta MU/\Delta t$, $\Delta\theta$, and $\Delta\theta/\Delta t$: 111 MU/min, 90° and 5.54°/s; 222 MU/min, 45° and 5.54°/s; 332 MU/min, 30° and 5.54°/s; 443 MU/min, 22.5° and 5.54°/s; 554 MU/min, 18° and 5.54°/s; 600 MU/min, 15° and 5°/s; 600 MU/min, 12.9° and 4.3°/s.

Figure 5 shows a fairly uniform intensity across the film except for the gaps between the strips. The radiation profile of the film, produced by a scanner and shown in Fig. 6 as the magenta line, was normalized (for the in-field portion of the profiles) to and superimposed on the profile of 14 × 20-cm open MLC field (dark blue line). This normalization is needed to remove the influence of nonflatness/asymmetry of the radiation field in the comparison of the exposures of the seven strips. Except for the gaps between the strips, the in-field profiles of the 7sQA and the open fields are closely matched. The ratio between the profiles of the 7sQA and that of the open field were computed at seven central positions for each of the seven strips. An average ratio was then calculated for each strip (from the ratios at the seven central positions). The seven average ratios were then averaged and normalized to unity. We then computed, for each strip, its deviation from unity. The mean deviation of the seven strips was 0.7%, with range of −1.0% to 1.1%.

The profiles of the seven-strip and the open-field films are different outside the penumbra, most likely because of increased scatter from the seven-strip MLC fields. Although the scatter would also affect the in-field portion, the contribution would by and large cancel out. Thus, to a very good approximation, the test shows that the same film-exposure can be delivered by the correct combinations of dose-rate and gantry speed.

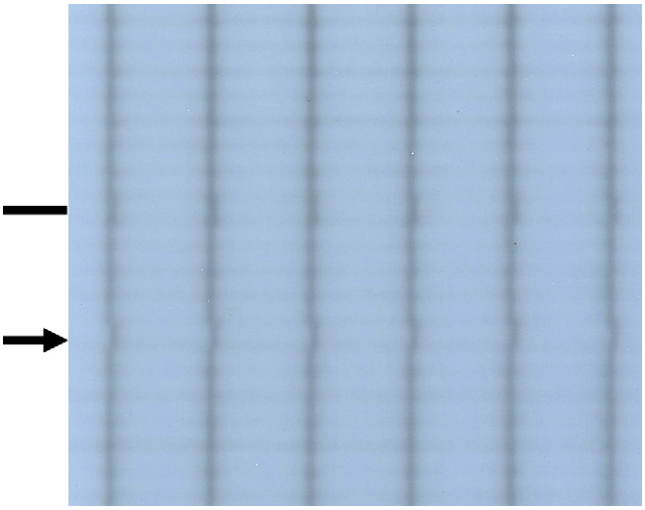

Fig. 4. A film exposed to the 1-mm-wide picket fence pattern with ''intentional'' errors in fence width and position.

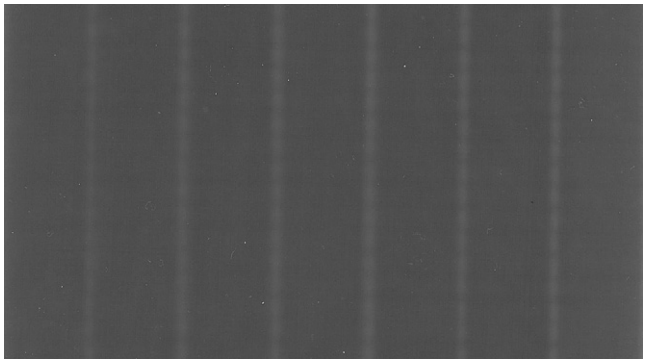

Fig. 5. Film exposed to a RapidArc QA plan, combining different dose-rates, gantry ranges, and gantry speeds, to give the same monitor unit (MU) to the different parts of the field.

Variable MLC leaf-speed during RapidArc

The data and their analysis from a film acquired with the LSQA plan are similar to those presented in Figs. 5 and 6, except that only four different parts were exposed to the same dose with the four sliding windows at leaf speeds of 0.46, 0.92, 1.84, and 2.76 cm/s. When the LSQA radiation profile was normalized to and superimposed on the profile of the corresponding open MLC field, the two profiles were closely matched. Similar data analysis was performed as described above, and the mean deviation of the four strips to the average was 0.4% (range, −0.8–0.8%).

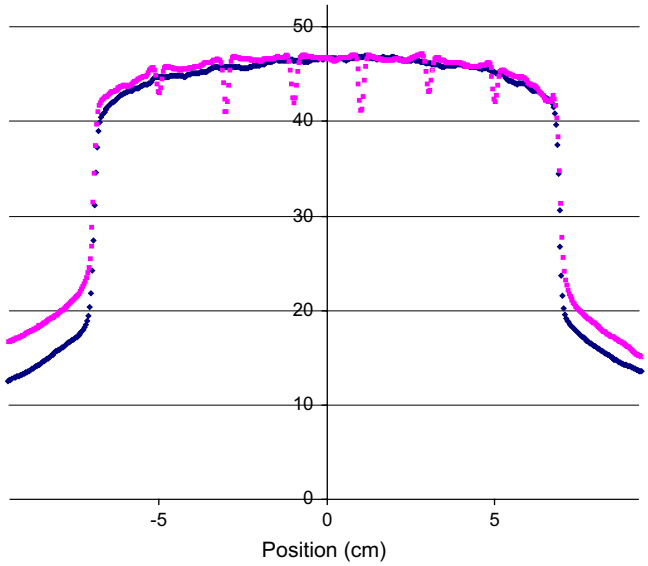

Fig. 6. Radiation profile of the film in Fig. 5 is plotted as the magenta line, normalized to and superimposed on the profile of the 14 × 20 cm open field (dark blue line).

Record of machine performance during RapidArc

The Dynalog from the Clinac, which recorded gantry angle and cumulative MU at each control point for comparison with the segmented treatment table, indicated mean standard deviations of ~0.04 MU and ~0.26° for all of the RapidArc QA plans.

The Dynalogs from the MLC control computer that recorded MLC positions and θ every 50 ms were analyzed using the Varian Argus. The analysis indicated precise position of all leaves for the picket fence test. Detectable leaf position errors were only present during the motion of the 1-mm strip to the next position with speed of ~2 cm/s. The histogram of >52,000 MLC positions showed that ~65% were within 0.05 mm, ~3% between 0.05 and 0.5 mm, ~28% between 0.5 and 1 mm, ~4% between 1.0 and 1.5 mm, and none >1.5 mm. For the 7sQA test, the MLC leaves are moved to the next position with the speed of ~1 cm/s. The histogram of MLC position deviations (~150,000 values) indicated ~90% of all errors <0.5 mm.

Analysis of MLC Dynalog file of Test 3 indicated that leaf position error increased linearly with leaf speed, and was highest when DMLC ran at 2.76 cm/s. Nevertheless, the histogram showed that ~ 87% were within 0.5 mm, ~7% between 0.5 and 1 mm, ~4% between 1.0 and 1.5 mm, ~2% >1.5 mm, and none >2.5 mm.

DISCUSSION

RapidArc, in a sense, is an extension of the IMRT and IMAT concepts (2, 6). In being able to plan and deliver IMRT in dynamic-arc mode with volumetric radiation fields, it offers important advantages over competing approaches (6, 12). Relative to either SMLC or DMLC IMRT using a fixed and limited number of fields, RapidArc will likely produce more conformal dose distributions, and obviate the question of the number and the directions of beams (12, 13). In addition, with RapidArc there is a significant reduction (by a factor of ≥2) in MU and beam-on time in the delivery of a treatment (12).

The advantage of the RapidArc approach, relative to tomotherapy, has been detailed by other investigators (12, 13). Compared with slice-by-slice tomotherapy, RapidArc is 5-15 times more efficient in terms of treatment time and monitor units (12). Another limitation in tomotherapy is in the constraint of >1-cm slice thickness, which compromises dose-conformality, relative to that achievable with MLC of 0.25-cm leaf-width. Another important advantage of RapidArc is the ability to delivering non–co-planar arcs (12, 13).

The delivery of RapidArc requires several advanced technologic capabilities: variable dose-rate, variable gantry speed, and dynamic MLC during gantry rotation. Commissioning and QA procedures of RapidArc must therefore address the reliability and accuracy of these parameters. In this study we designed procedures to achieve the following: (*1*) test MLC positional accuracy, (*2*) assess the accuracy of variable dose-rate, and (*3*) evaluate the accuracy of MLC leaf speed. Our protocol adopts a step-by-step approach, in that the validity of Test 2 depends on the success of Test 1, and the validity of Test 3 depends on the success of Tests 1 and 2. Successful implementation of these tests provides assurance that the Clinac has the functional ability to deliver RapidArc treatments accurately.

The picket fence test has been successfully adapted for use in RapidArc (16). By comparing the tests in stationary and rotational gantry modes, the effect of gantry rotation on leaf position accuracy was assessed. By performing a double exposure, irradiating the same film in both stationary and rotational gantry modes but with different field lengths, a visual assessment of possible differences can be performed (Fig. 3). In addition, Fig. 4 shows that 0.5 mm ''intentional'' errors can be easily discerned in the RapidArc picket fence test, indicating that any increase in MLC uncertainty is much less than 0.5 mm, and that this test is sensitive enough to detect errors of ~0.5 mm.

Tests 2 and 3 were designed such that the same dose was delivered to different portions of a film, with the advantage that the dynamic range and gamma calibration for film dosimetry are obviated. In Test 2, that used different $\Delta MU/\Delta t$ and $(\Delta\theta/\Delta t)$ to give the same dose to seven 1.8-cm strips, the normalized dose showed good agreement to ~0.7%, providing strong evidence that variable dose-rate and gantry speed can be accurately controlled during RapidArc.

Having established the accuracy in DMLC position and dose-rate, we evaluated the use of different MLC speed in Test 3. Analysis of the radiation pattern relative to that of the corresponding open field, indicated good agreement in the delivered dose to ~0.4% for different combinations of MLC leaf speeds (0.46, 0.92, 1.84, and 2.76 cm/s), dose-rates (138, 277, 554 MU/min), and field widths (3 and 4.5 cm). Thus, accuracy of leaf speed during RapidArc has been validated.

Although film is used in this study, the same tests can be and has been performed the Varian EPID. As to radiochromic film, its relative low radiosensitivity is an issue, although plans could be redesigned to deliver a higher dose.

Thus far we have not differentiated between commissioning and QA procedures. But as we gain experience, it is likely that the different tests can be performed with different regularity, just as what is practiced in other radiotherapy equipment commissioning and QA, including IMRT.

This is an initial attempt in designing a commissioning and QA protocol. There are areas for refinement and improvement in the future, by us or by other investigators. Nevertheless this prototypical protocol provides the first step for medical physicists to ensure the accurate, reliable, and safe use of RapidArc. Finally, the above are intended only for Clinac commissioning and QA and not for patient-specific dosimetry. For the latter, additional measurements need to performed using calibrated matrix dosimetry devices such as those used in IMRT QA of clinical treatment plans.

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