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Can cost make a difference dosimetrically? Volumetric modulated arc therapy study for multileaf collimators of various widths for head and neck and prostate cancers

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ABSTRACT

Cancer is a global health issue that disproportionately kills based on stage of disease, cellular pathology, and genetics, to name a few. Another variable to consider in this ongoing fight is treatment machine complexity that leads to elevated development and purchasing cost, leading to a reduced use. Reducing the complexity (in hopes of lowering costs) would benefit underdeveloped, low- and middle-income countries by introducing newer treatment technology, as their currently accepted standards do not meet standards of more advanced, developed countries. In this study, unilateral head and neck (H&N), and prostate cases using volumetric modulated arc therapy (VMAT) were tested with multiple segment widths of 5, 10, 15, and 20 mm to create treatable plans. Pinnacle 9.10v was used for planning purposes. A total of 12 cases were planned with varying multileaf collimator (MLC) widths. Treatment plans were evaluated retrospectively. Results show that altering the MLC widths from 5 through 20 mm produces both comparable and treatable plans up to 99% and 98% target coverage for H&N and prostate, respectively, albeit clinically significant hot spots were shown to increase with increasing segment width. Furthermore, the results show that increasing widths can produce comparable treatment plans as measured against our current Food and Drug Administration (FDA)–approved treatment devices—leading to an increase in treatment efficacy in economically underdeveloped countries.

Introduction

Cancer is a global health issue that disproportionately kills in underdeveloped nations. Each year, 5 of the 7 million cancer deaths in the world occur in low- and middle-income countries.[1] The World Health Organization (WHO), in conjunction with the International Agency for Research on Cancer, concluded that at least 50% of patients with cancer in such nations would benefit from at least 1 course of radiotherapy. The same study showed an improved efficacy when used in conjunction with other methods, strongly endorsing the use of adjuvant radiotherapy for cancer treatment. Barriers to availability of radiotherapy in these countries are attributed primarily to costs, namely facilities, staff, education, and equipment cost. Equipment costs were further broken down to include that of maintenance for treatment machines—up to $91,740 annually.[2]

Another variable to consider is treatment machine complexity that increases cost and leads to a decreased use. Linear accelerator (linac) treatment machines are equipped with multileaf collimators (MLC), which are motorized tungsten segments used in dose modulation. Complex linacs use more MLC segments of smaller widths. These linacs, housing up to160 segments, can cost up to $4.1 million, with the cost of a single motorized leaf segment ranging up to $10,000.[3,4] Reducing the complexity of these treatment machines with fewer, larger-width MLC segments should cut costs. These reduced costs would benefit underdeveloped countries by introducing newer treatment technology that meets the treatment standards of more advanced, developed countries.

Conventional 3-dimensional conformal technique was preferred in radiotherapy before the prevalence of intensity-modulated radiation therapy (IMRT). IMRT uses a computer-aided optimization process "to determine customized, nonuniform fluence distributions to attain certain specified dosimetric and clinical objectives."[5]

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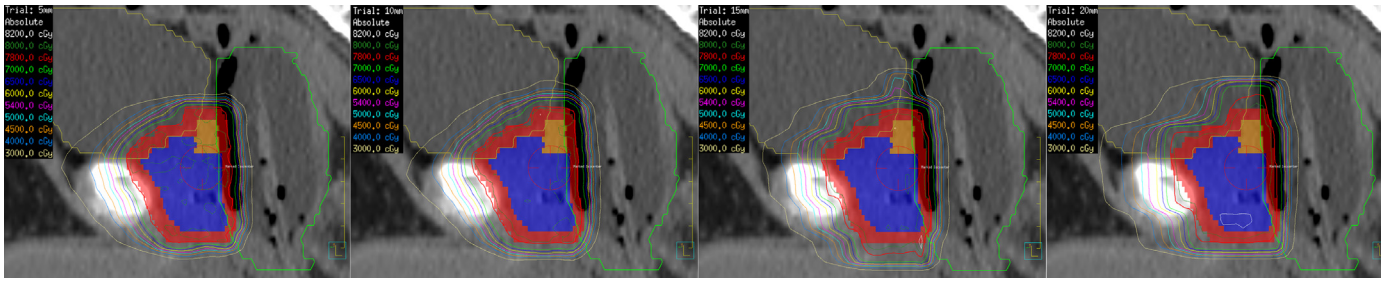

Fig. 1. Sagittal view of a prostate plan centered on treatment isocenter comparing isodose distribution at 5-, 10-, 15-, and 20-mm MLC widths.

Volumetric modulated arc therapy (VMAT) has emerged as an advanced IMRT modality, which functions through delivery of a continuous beam of radiation through gantry rotations, variable speed, variable dose rate, and MLC positioning.[6-9]

Smaller MLC segment widths result in greater modulation and greater sparing of critical structures near the target.[10–12] It is this fact that has driven the commission of treatment machines with ever increasing complexity—as many as 160 MLC segments of 2.5-mm width. Historic data, however, show in larger target volumes like the prostate, large-width (10 mm) MLC segments produce comparable treatment plans with those produced using small-width (5 mm) segments.[13] Additionally, the most significant sparing occurs with the smallest critical structures, resulting in only a marginal improvement in control for most structures.[14] The purpose of this comparative study is to discover whether reducing complexity and cost of linacs by increasing MLC segment widths up to 20 mm, for which no data exist, would make a difference dosimetrically.

Methods and Materials

In this study, 12 previously treated patients were selected. Among them, 6 patients with cancer in head and neck (H&N) site were definitively treated for unilateral parotid and submandibular disease and were simulated in the supine position with a custom H&N immobilization mask in place. Another 6 patients with cancer in prostate sites were definitively treated for prostate and proximal or proximal and distal seminal vesicle targets and were also simulated in the supine position. All patients were simulated using a GE-computed tomography scanner with 3-mm slice widths.

Physician-approved contours were used for all target volumes (clinical target volume [CTV], CTV_{sub}, and planning target volume) and critical structures/organs. Critical organs include the brainstem, cochlee, larynx, lenses, mandible, parotid glands, submandibular glands, and spinal cord for H&N. Critical organs for the prostate cases include bladder, femoral heads, and rectum. All H&N patients were planned to a total dose of 60 Gy in 30 fractions, which is further specified as 60 Gy to CTV_{60}, 57 Gy to the high-risk volume CTV_{57}, and 54 Gy to the low-risk volume CTV_{54}. All patients with prostate cancer were planned to a total dose of 78 Gy in 39 fractions to the CTV, which included the prostate and seminal vesicles, also the distal seminal vesicles in some cases.

All patients were reoptimized using VMAT, and were performed on the Phillips Pinnacle[3] 9.10v treatment planning software. Smart Arc Optimization algorithm was used with 6-MV photon beams, 2 full arcs for prostate sites and 2 partial arcs for H&N. All arc start and stop angles were determined by angles used in the original, approved plan. Virtual MLC widths of 5, 10, 15, and 20 mm were created and modeled for a Varian 2100 series linac. These virtual widths were uniform throughout the full length of the field, which differs from many current machines that have larger-width MLCs proximal to the jaw edge and smaller-width MLCs proximal to the central axis.

The planning goals were to achieve the required target volume coverages of 99% to each target of H&N and 100% to the prostate target. The secondary planning goal was to reduce the critical organ dose within Radiation Therapy Oncology Group [RTOG] defined constraints without compromising target coverage. After both objectives were met, the critical organ doses were reduced to as low as reasonably achievable (as low as reasonably achievable [ALARA] principle) without compromising target coverage. This process was repeated for each width (5, 10, 15, and 20 mm) for each patient.

Dosimetric data for means and standard deviations were collected and analyzed using a paired 2 sample t-test for unequal variances with $\alpha = 0.05$. The t-test analysis was chosen as the study has a small sample size. Unequal variances were chosen owing to the significant changes inherent in the MLC width model.

Results

Figure 1 displays isodose distributions for a prostate plan at 5-, 10-, 15-, and 20-mm MLC widths. A reduction in conformity of the isodose lines around the target occurs, resulting in a higher volume of normal tissue and critical organ irradiation, as the MLC widths increase. Additionally, there was an increase in clinically significant hot spots owing to the loss of modulation with increasing MLC widths. Notably, the appearance of step-like formations appear at 15-mm width, with the 20-mm width displaying these “steps” most prominently. All trials were clinically treatable.

Figure 2 displays isodose distributions for a H&N plan at 5-, 10-, 15-, and 20-mm MLC widths. A reduction in conformity of the isodose lines around each target, resulting in an increase in clinically significant hot spots for each target, as the MLC widths increase. A higher volume of normal tissue and critical organ irradiation occurred owing to the loss of modulation inherent in each increasing segment width as well. Notably, the appearance of step-like formations appear at 15-mm width, with the 20-mm

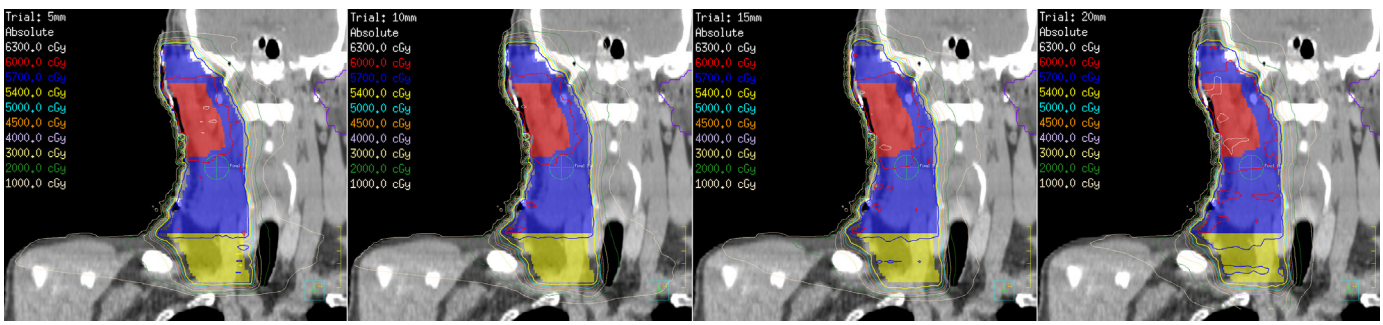

Fig. 2. Coronal view of a H&N plan centered on treatment isocenter comparing isodose distribution at 5-, 10-, 15-, and 20-mm MLC widths.