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A Study of Unplanned Radiation Dose Received From Image Guided Radiotherapy Procedures (MV CBCT and EPI)

Rolina K. Al-Wassia, FRCPC, and **Camelia Constantinescu[1],** PhD

Department of Radiology, Faculty of Medicine, King Abdulaziz University
[1]Department of Oncology, King Faisal Specialist Hospital & Research Center, Jeddah, Saudi Arabia
ralwassia@kau.edu.sa

Abstract. To quantify and compare the doses to the tumor and the surrounding critical organs; a patient's dose resulting from the orthogonal pair portal and megavoltage cone beam computerized tomography imaging techniques. Calculation based on a 6 MV Oncor linear accelerator equipped with an amorphous silicon flat panel, and done on Eclipse 3-D treatment planning system. 18 patients analyzed on three different treatment sites (head and neck, thorax, and pelvis). Data from 6 patients for each treatment site were used to calculate the mean doses. Calculations were done for: integral dose, patient's maximum dose, dose at the isocenter, and mean dose to the tumor and each critical organ. The integral dose and isocenter dose per MU were higher for orthogonal pair technique than for megavoltage cone beam computerized tomography, for all treatment sites. For both techniques, the doses to the isocenter per MU were higher for head and neck and thorax than for the pelvis. Maximum dose difference to the patient showed greater variation for head and neck, but not for thorax and pelvis. The dose per MU to the tumor (GTV/CTV/PTV) or to the critical organs located closer and posterior to the tumor were diminutive for both techniques. The area covered by the 5cGy isodose line of the megavoltage cone beam computerized tomography technique was larger, including more volume of critical organs. The relatively high dose regions generated by megavoltage cone beam computerized tomography occur inside critical organs and tend to be larger than those generated by the orthogonal pair technique.

Keywords: Cone beam computed tomography, Integral dose, Image-guided radiation therapy.

Correspondence & reprint request to: Dr. Rolina Al-Wassia
P.O. Box 80215, Jeddah 21452, Saudi Arabia

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Introduction

The issue of the dose delivered to the rest of the body during external beam radiation therapy is presently scattered widely through the literature[1]. This concomitant "extra-target" dose includes external linac head leakage and scatter, internal direct and scattered therapy dose outside the target volume, as well as non-therapeutic doses from imaging for planning and delivery. Total concomitant dose is increased with the introduction of more imaging procedures to the treatment process. However, much of this exposure is only qualitatively monitored, and some is not monitored at all. Because this cumulative extra-target dose has a negative biological effect even within the context of radiation therapy, it is important to assess its cost and benefit.

Radiographic image guidance has emerged as a new paradigm for patient positioning, target localization, and external beam alignment in radiation therapy. Although widely varied in modality and method, all radiographic guidance techniques have one thing in common: they can give a significant radiation dose to the patient. As with all medical uses of ionizing radiation, the general view is that this exposure should be carefully managed. The philosophy for dose management adopted by the diagnostic imaging community is summarized by as low as reasonably achievable (ALARA). But unlike the general situation with diagnostic imaging and image-guide surgery, image-guided radiation therapy adds the imaging dose to an already high level of therapeutic radiation. interplay between increased imaging and improved therapeutic dose conformity, suggests the possibility of optimizing rather than simply minimizing the imaging dose. For this reason, the management of imaging dose during radiation therapy is a different problem than its management during routine diagnostic or image-guided surgery[2].

The imaging dose received as part of a radiation therapy treatment has long been regarded as negligible, and thus, has been quantified in a fairly loose manner. On the other hand, radiation oncologists analyze the therapy dose distribution in detail, hence the introduction of more intensive imaging procedures for image-guided radiotherapy (IGRT) required more attention in evaluating therapeutic and imaging doses[3-10].

Image-guided radiotherapy (IGRT) makes use of many different imaging techniques, using modalities ranging from portal imaging to fluoroscopy to megavoltage cone beam computerized tomography (MV

CBCT), and following regimens as simple as a single setup image or as complex as intra-fraction tumor tracking. The total imaging radiation dose experienced by a patient can include multiple computerized tomography (CT) scans for planning, pre-treatment fluoroscopic studies to analyze tumor motion, and a series of inter-fraction or intra-fraction images for target localization. The delivery of this dose can be spread out over several weeks during conventional radiation therapy or confined to a short time for hypo-fractionated radiation therapy and radiosurgery. Under these circumstances, it is no longer safe to consider the dose from only one imaging procedure at a time, or to assume that the cumulative imaging dose is negligible compared to the therapeutic dose[2].

The aim of the current study is to compare in a retrospective way radiation dose delivered to patients during their imaging procedures. Radiation therapy using two different modalities: two orthogonal pair beams versus MV CBCT regarding the integral dose, maximum dose to the patient, dose at the isocenter, and mean dose to the tumor and each critical organ.

Materials and Methods

Compare and quantify the doses to the tumor and the surrounding critical organs, resulting from the orthogonal pair and MV CBCT techniques, 18 patients representing three different treatment sites (head and neck, thorax, and pelvis) were analyzed. Patients were accrued retrospectively from Radiation Therapy Unit at King Abdulaziz University Hospital, Jeddah, Saudi Arabia, during the period January to December 2007. Data from 6 patients for each treatment site were used to calculate the mean doses. Calculations were done for: the integral dose, maximum dose to the patient, dose at the isocenter, and mean dose to the tumor and each critical organ.

In addition, because the actual MUs used in MV CBCT may vary with the treatment site and the imaging protocol, the dose per MU has been reported. Dose per MU provides a means for easily scaling the calculated dose results to other MU settings.

The calculated dose to the patient resulted from the orthogonal pair and the MV CBCT imaging techniques, both based on a 6 MV Oncor linear accelerator equipped with an amorphous silicon flat panel. All calculations were done on Eclipse 3-D treatment planning system, using Photon Pencil Beam Convolution algorithm version 8.1.17 with a

heterogeneity correction by modified Batho method, and a size of the calculation grid of 0.5 cm.

For the orthogonal pair technique, an AP and a lateral field were created, each with a field size of 27 x 27 cm^2 and a beam on time of 3 MU.

For the MV CBCT technique, a 200 degree arc beam was created, from 270 degrees to 110 degrees in a clockwise direction and a beam on time of 8 MU. The field size was set to 27 x 27 cm^2.

Results

Comparing the two techniques, the integral dose per MU and the dose to the isocenter per MU were higher for orthogonal pair technique than for MV CBCT, for all treatment sites. For both techniques, the dose to the isocenter per MU were higher for head and neck (because of small separation) and for thorax (because of lung density) than for pelvis. However, the difference of maximum dose to the patient showed greater variation for head and neck, but not for thorax and pelvis. Furthermore, the doses to critical organs were larger for organs whose locations were anterior, and farther from the tumor or the isocenter. In contrast, the dose per MU to the tumor (GTV/CTV/PTV) or to the critical organs located closer and posterior to the tumor were very small for both techniques (Table 1).

Table 1. Value and standard deviation of the relative dose (cGy/MU) between MV CBCT imaging, and orthogonal portal imaging for tumor (GTV/CTV/PTV) and critical organs.

	Head and neck (6 patients)	
	MV CBCT	Portal imaging
Dose @ isocenter	1.12 ± 0.03	1.22 ± 0.02
Max. dose	1.36 ± 0.27	1.53 ± 0.02
Eye	0.96 ± 0.31	1.07 ± 0.38
Lens	0.86 ± 0.35	1.10 ± 0.26
Spinal cord	1.03 ± 0.07	1.16 ± 0.05
Skin	1.32 ± 0.03	1.45 ± 0.04
	Lung (3 patients)	
	MV CBCT	**Portal imaging**
Dose @ isocenter	0.94 ± 0.02	1.00 ± 0.05
Max. dose	1.37 ± 0.02	1.63 ± 0.02
Lung	1.25 ± 0.09	1.35 ± 0.18
Spinal cord	1.00 ± 0.14	1.05 ± 0.11
Skin	1.29 ± 0.03	1.55 ± 0.03

Table 1. ***(Continuation)*** **Value and standard deviation of the relative dose (cGy/MU) between MV CBCT imaging and orthogonal portal imaging for tumor (GTV/CTV/PTV) and critical organs.**

	Mediastinum (3 patients)	
	MV CBCT	**Portal imaging**
Dose @ isocenter	0.92 ± 0.01	1.02 ± 0.05
Max. dose	1.36 ± 0.01	1.66 ± 0.01
Lung	1.19 ± 0.04	1.32 ± 0.23
Spinal cord	1.00 ± 0.14	1.05 ± 0.11
Skin	1.30 ± 0.10	1.57 ± 0.02
	Cervix (3 patients)	
	MV CBCT	**Portal imaging**
Dose @ isocenter	0.86 ± 0.01	0.92 ± 0.02
Max. dose	1.36 ± 0.00	1.64 ± 0.01
Bladder	1.08 ± 0.09	1.20 ± 0.06
Rectum	0.79 ± 0.02	0.90 ± 0.03
Skin	1.29 ± 0.03	1.55 ± 0.05
	Prostate (3 patients)	
	MV CBCT	**Portal imaging**
Dose @ isocenter	0.81 ± 0.04	0.86 ± 0.04
Max. dose	1.35 ± 0.00	1.67 ± 0.02
Bladder	1.13 ± 0.07	1.20 ± 0.08
Rectum	0.85 ± 0.04	0.94 ± 0.04
Skin	1.30 ± 0.02	1.55 ± 0.02

Because of the greater MUs employed in the MV CBCT technique, the integral dose from the MV CBCT technique was higher than that from orthogonal pair technique. The dose difference ranged from 6.36 ± 0.16 cGy to 10.65 ± 0.05 cGy for MV CBCT technique and from 5.63 ± 0.23 cGy to 9.43 ± 0.13 cGy for orthogonal pair technique, for various organs (Table 2).

Compared with the orthogonal pair technique, the area covered by the 5 cGy isodose line of the MV CBCT technique is larger, including more volume of critical organs. With the orthogonal pair technique, the isocenter is located at the center of the tumor, thus contributing higher dose to the tumor, but lesser doses to the normal tissue away from the tumor. Moreover, the high dose area is located at the proximal corner of the rectangular area intersected by the two orthogonal beams. In contrast, because of the anterior arc, the high dose area in the MV CBCT technique is located anterior to the anatomy, where it will contribute more doses to the more anterior critical organs.

Table 2. Value and standard deviation of the absolute dose (cGy) between MV CBCT imaging with 8 MUs and orthogonal portal imaging with 6 MUs for tumor (GTV/CTV/PTV) and critical organs.

	Head and Neck (6 patients)	
	MV CBCT	Portal imaging
Dose @ isocenter	9.04 ± 0.26	7.30 ± 1.46
Max. dose	10.92 ± 0.18	9.22 ± 0.18
Eye	7.77 ± 2.54	6.47 ± 2.32
Lens	6.98 ± 2.86	6.65 ± 1.67
Spinal cord	8.25 ± 0.55	6.98 ± 0.32
Skin	10.65 ± 0.05	8.72 ± 0.28
	Lung (3 patients)	
	MV CBCT	Portal imaging
Dose @ isocenter	7.56 ± 0.23	6.06 ± 0.33
Max. dose	11.03 ± 0.16	9.83 ± 0.06
Lung	10.06 ± 0.73	8.11 ± 1.08
Spinal cord	8.23 ± 1.12	6.33 ± 0.66
Skin	10.33 ± 0.23	9.34 ± 0.29
	Mediastinum (3 patients)	
	MV CBCT	Portal imaging
Dose @ isocenter	7.40 ± 0.10	6.16 ± 0.33
Max. dose	10.90 ± 0.1	10.00 ± 0.10
Lung	9.52 ± 0.28	7.92 ± 1.38
Spinal cord	8.23 ± 1.12	6.33 ± 0.66
Skin	10.46 ± 0.16	9.43 ± 0.13
	Cervix (3 patients)	
	MV CBCT	Portal imaging
Dose @ isocenter	6.96 ± 0.22	5.56 ± 0.15
Max. dose	10.90 ± 0.00	4.80 ± 0.10
Bladder	8.63 ± 0.36	7.28 ± 0.43
Rectum	6.36 ± 0.16	5.44 ± 0.27
Skin	10.33 ± 0.39	9.36 ± 0.36
	Prostate (3 patients)	
	MV CBCT	Portal imaging
Dose @ isocenter	6.50 ± 0.30	5.23 ± 0.27
Max. dose	10.86 ± 0.06	10.06 ± 0.14
Bladder	9.06 ± 0.56	7.23 ± 0.43
Rectum	6.83 ± 0.33	5.63 ± 0.23
Skin	10.46 ± 0.06	9.38 ± 0.15

The high dose area in orthogonal portal imaging is always located inside the tumor or close to it; hence, the extra dose will not be a significant issue in clinical treatment. However, with MV CBCT imaging, the high dose area might be inside normal critical organs located away from the tumor (Fig. 1, 2). The effect could be significant

and could possibly lead to secondary malignancies, depending on the threshold dose of the irradiated organs. If high doses are necessary for verification of patient treatment location, then the extra dose should be calculated and evaluated in treatment planning to ensure that it does not exceed the tolerance dose of sensitive organs (Fig. 3).

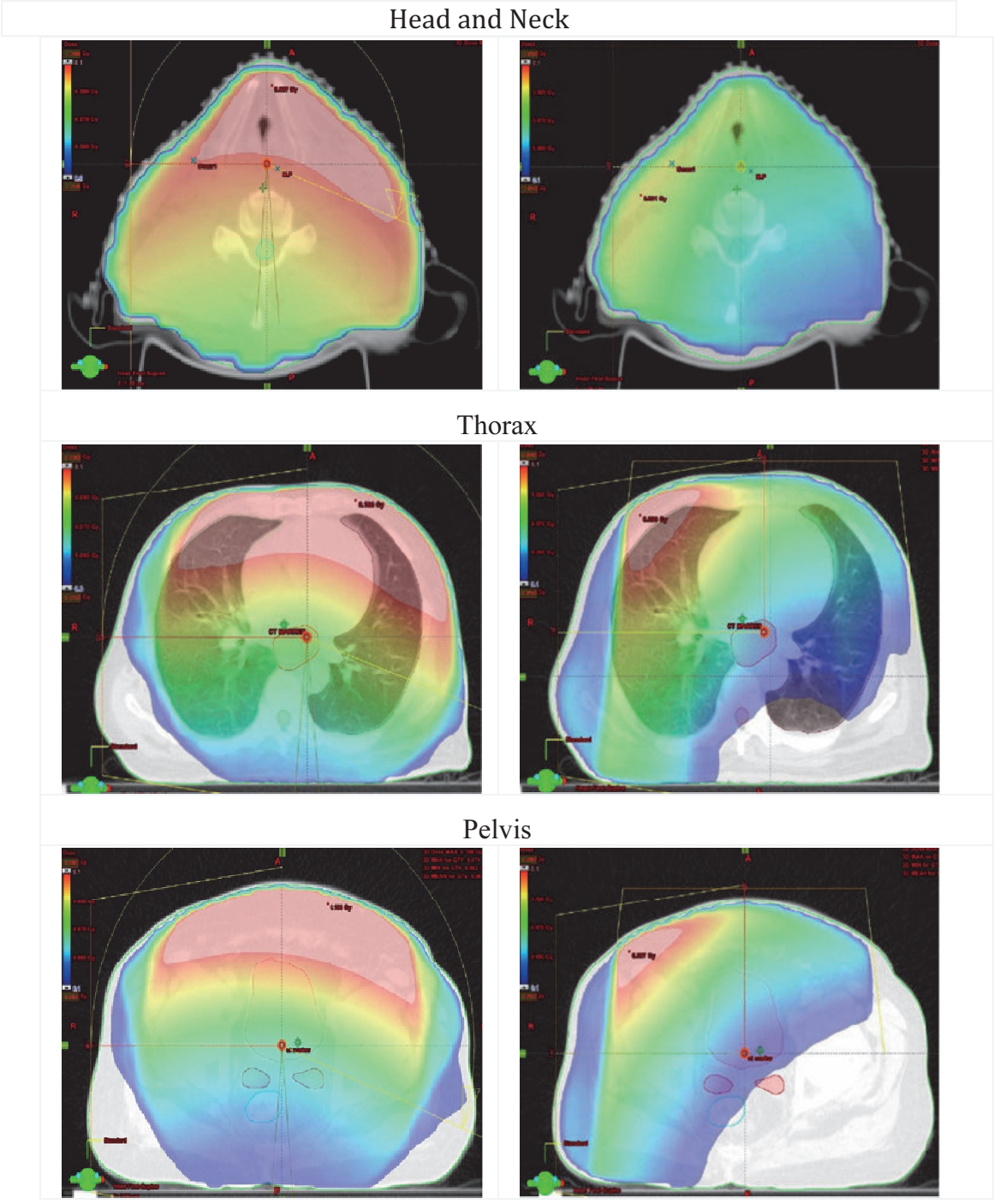

Fig. 1. The 2D absolute dose distribution of transverse central slice evaluated in various treatment sites using MV CBCT imaging with 8 MUs (left panels) and orthogonal portal imaging with 6 MUs (right panels).

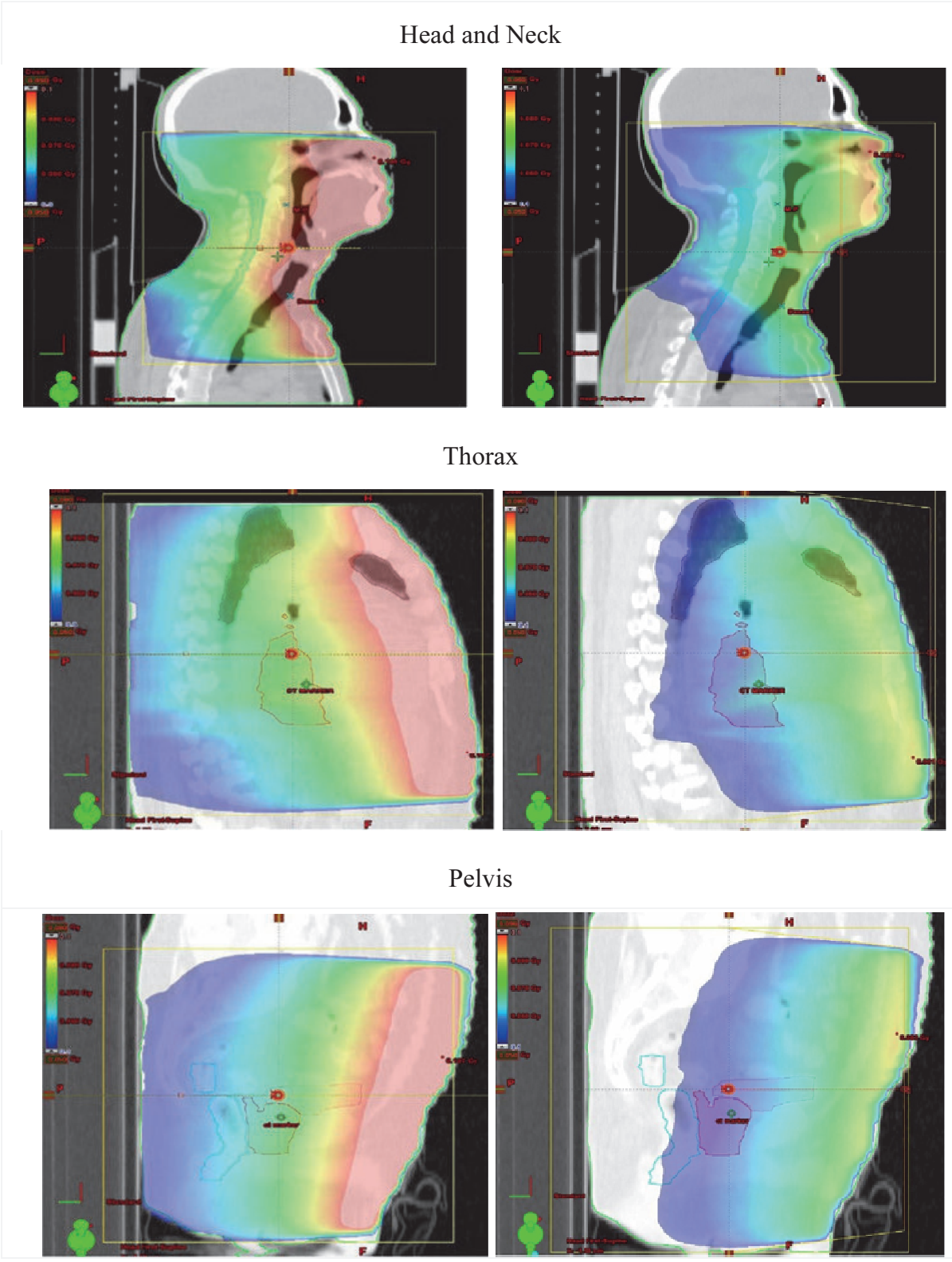

Fig. 2. The 2D absolute dose distribution of sagital central slice evaluated in various treatment sites using MV CBCT imaging with 8 MUs (left panels) and orthogonal portal imaging with 6 MUs (right panels).

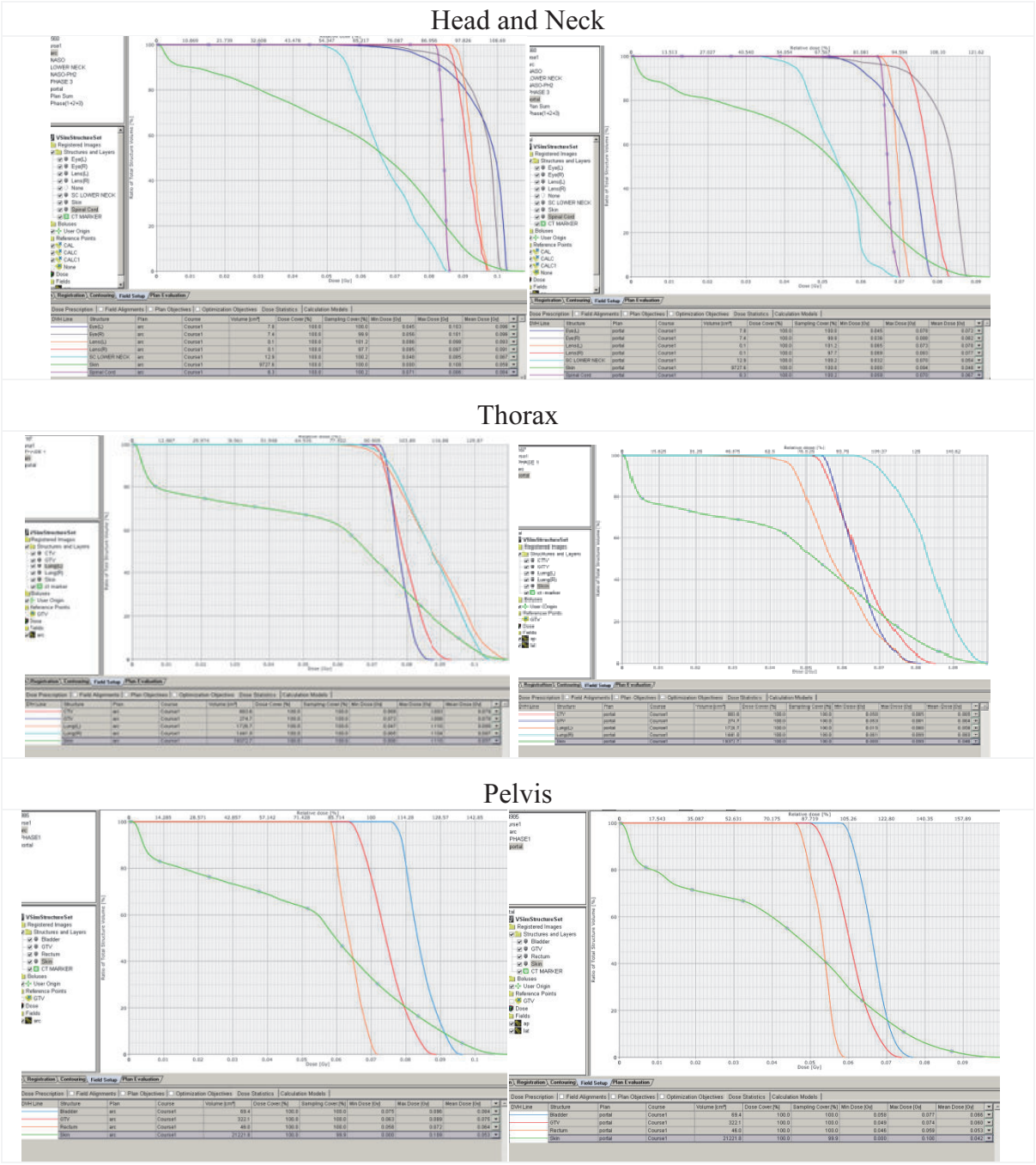

Fig. 3. The dose-volume histogram of tumor (GTV/CTV/PTV) and all critical organs evaluated in various treatment sites using MV CBCT imaging with 8 MUs (left panels) and orthogonal portal imaging with 6 MUs (right panels).

Discussion

Exposure to ionising radiation presents two potential health hazards: The risk of deterministic injury and the stochastic risk of inducing cancer or genetic defects. Stochastic risk enters more broadly as a result of

concomitant dose from both the therapy beam and from the imaging procedures.

Even though radiation therapy patients are already being exposed to very high and localized doses of radiation, the additional radiation from imaging has an associate risk and should be kept low[11]. Dose minimization, however, must be within a context of relative hazard versus benefit that will vary from patient to patient. A 20-years-old being treated *via* image guided radio surgery for an arterio-venous malformation assumes a stochastic risk from imaging radiation that is fundamentally different from a 70 year old being treated *via* IG IMRT for prostate cancer. Children are ten times more radiation sensitive than adults, and girls are more sensitive than boys[12,13]. Therefore, imaging dose should be managed on a case-by-case basis.

This study calculated doses, dose distributions, and DVHs resulting from both the MV CBCT and orthogonal pair techniques for three treatment sites. The calculation for the orthogonal pair technique was based on 6 MUs and that for MV CBCT on 8 MUs. The latter was considered to be feasible for routine clinical application, providing good image quality while keeping the dose to the patient relatively low.

The high dose area in orthogonal portal imaging is always located inside the tumor or close to it, so that the extra dose will not be a significant issue in clinical treatment. However, with MV CBCT imaging, the high dose area was shown to be inside normal critical organs located away from the tumor. The effect could be significant and could possibly lead to secondary malignancies, depending on the threshold dose of the irradiated organs. If high doses are necessary for verification of patient treatment location, then the extra dose should be calculated and evaluated in treatment planning to ensure that it does not exceed the tolerance dose of sensitive organs.

In our selected cases, the high dose area from the orthogonal pair technique was always located inside the tumor; while with MV CBCT, the high dose area was located outside the tumor. Therefore, the potentially higher doses to critical organs from MV CBCT images should be properly analyzed, to ensure that they do not exceed the tolerance dose when therapy is delivered using that technique. On the other hand, to obtain good image quality, higher MUs with MV CBCT might be necessary. The absorbed dose from the tumor and other critical organs

should be calculated accordingly in the treatment plans. Images by MV CBCT are a great tool for 3-D verification of patient treatment position, but might have a higher chance of increasing the dose to normal tissues during image acquisition.

Image-guided radiotherapy (IGRT) with radiographic modalities adds more radiation dose to the already high dose burden to the patient, in ways that are fundamentally different from the therapy itself. Good medical practice demands that the negative effects of the concomitant dose be reduced as much as possible[14].

A similar study showed close results to the current study that was done by Peng *et al.*[15] who found also that the radiation dose to critical organs outside the treatment filed was higher in MV CBCT imaging as compared to orthogonal pair technique.

Another study by Isambert[16] looked at the effect of MV CBCT images on dose sum delivery using different schedule and 5 MU setting. They concluded that the dose will increase the isocenter by 3.7 cGy and other areas close to the skin; the dose reached to 6 cGy. This proofs that the highest dose can be deposited in the areas of normal structures and exceed the tolerance of the organs.

Morin *et al.*[17] proposed a useful feature that can be used in the treatment planning system, which is calculating the extra dose that will result from MV CBCT. Similarly, by using a compensation factor that reduces the number of MU per treatment beam per fraction which can results in eliminating the imaging dose to the desired organs or to a focus on a specific region of interest resulting in a more accurate dose delivery.

Conclusion

From our analysis, the relatively high dose regions generated by MV CBCT occur inside critical organs and tend to be larger than those generated by the orthogonal pair technique. Radiation-induced secondary neoplasm is always a concern in radiation therapy. Because of the potential biologic effects caused by the small dose from the imaging process, the extra dose burden to the critical structures should be monitored carefully.

This study provides a quantitative analysis on the extra radiation burden caused by current verification procedures and recommends that conservatively designed IGRT procedures need to be implemented.

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دراسة عن جرعة الإشعاع غير المخطط له من إجراءات التصوير الإشعاعي الاسترشادي باستخدام تقنية ال (MV CBCT و EPI)

رولينا كمال الوسية، و كاميليا قستنتيسيو[1]

قسم الأشعة ، كلية الطب، جامعة الملك عبدالعزيز

[1] *قسم الأورام، مستشفى الملك فيصل التخصصي ومركز الأبحاث*

جدة – المملكة العربية السعودية

المستخلص. الهدف: لتحديد ومقارنة جرعات الأشعة الممتصة بالورم وبالأعضاء المحيطة الناتجة عن استخدام الإشعاع الإرشادي (Portal images) والتصوير المقطعي (MV CBCT).

المواد والطرق: تم حساب الجرعة الناتجة عن أخذ أشعات باستخدام ال (PI) و(MV CBCT) لمناطق مختلفة من الجسم تعالج بالإشعاع. وأجريت العمليات الحسابية باستخدام برنامج ال (Eclipse 3D). تم تحليل ١٨ مريضًا يمثلون ثلاثة مواقع مختلفة من الجسم، وتم تحديد الجرعة النهائية والجرعة القصوى والجرعة في إلى منتصف الورم ال (Isocenter) ومتوسط الجرعات للورم ولكل الأعضاء الحرجة.

النتائج: الجرعة الكاملة والجرعة إلى منتصف الورم لكل وحدة (MU) أعلى لتقنية ال (Portal Images) عن تقنية ال (MV CBCT).

ظهر الفرق بشكل أكبر بين التقنيتين في حسابات الجرعة القصوى للمريض في منطقه الرأس والعنق وليس في منطقة الصدر

والحوض. وكانت الجرعة لكل (MU) داخل منطقة الورم، أو إلى الأجهزة الحرجة التي تقع قرب أو خلف الورم مباشرة صغيرة جدًا لكل التقنيات. المنطقة التي يشملها خط الجرعة المساوي ل 5cGy بالتقنيتين كان يحوي المناطق الأمامية والبعيدة عن الورم بما فيه الأعضاء الحرجة.

الخلاصة : المناطق التي تأثرت بجرعة عالية نسبيًا باستخدام. تقنية ال (MV CBCT) تميل إلى أن تكون أكبر من تلك الناتجة عن استخدام تقنية ال (Portal imaging).