Original article

Comparison of calculated dose between planned adaptive software and helical tomotherapy treatment planning programs

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Purpose To compare between the calculated dose of planned adaptive software on MVCT images and the helical tomotherapy planning dose calculated on kVCT images.

Methods The patients included in this study were 14 head and neck cancer cases treated by helical tomotherapy. All the planning doses were calculated by the planning station on kVCT data sets for PTV70, PTV59.4 and PTV54. The MVCT datasets were acquired by the helical tomotherapy system. The merged image between the kVCT and MVCT images was used for planned adaptive calculation. D95 of all PTVs, D50 of the parotid glands and D2 of the spinal cord were evaluated from a dose-volume histogram (DVH). These dosimetric parameters were compared using Pearson's correlation.

Results The average D95 (cGy/fraction) of kVCT and MVCT two-dose calculation for PTV70, PTV59.4 and PTV54 was 212.1, 179.9 and 164.9, and 215.8, 183.3 and 162.9, respectively. The average D50 (cGy/fraction) of kVCT and MVCT two-dose calculation for the right and left parotid glands was 89.6 and 91.0, and 85.9 and 87.1 cGy/fraction, respectively. The average D2 (cGy/fraction) of kVCT and MVCT two-dose calculation for the spinal cord was 96.1 and 98.0 cGy/fraction, respectively.

Conclusions The comparison of dosimetric results in this study demonstrated that the MVCT calculated dose by planned adaptive software correlates with the planning dose on kVCT, and they can be substituted by each other. **Chiang Mai Medical Journal 2015;54(1):9-15**.

Keywords: helical tomotherapy, planned adaptive, MVCT, dosimetric parameters

Introduction

In radiotherapy, treatment planning is generated for each patient and used over the treatment course, assuming that patient has static anatomy throughout it. Actually, several patients have anatomic changes during the treatment course, due to weight loss and tumor shrinkage. Using the initial treatment plan can cause dose deviation under or over the target volumes and organ at risk (OAR)[1-2]. Intensity-modulated radiotherapy (IMRT) is used as routine clinical treatment of head and neck cancer (HNC). This technique provides a highly conformal dose resulting in a sharp dose gradient between target volumes and the

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Received: June 2, 2014, Accepted: September 8, 2014.

OAR[3]. Therefore, the IMRT plan requires an accurate dose delivery procedure.

Helical tomotherapy (HT) is the IMRT rotational delivery (Arc-base IMRT) with a spiral fan beam, which is similar to a helical CT scanner. A helical tomotherapy unit can acquire megavoltage computed tomography (MVCT) images of the patient in a treatment position and this information is used as image-guided radiotherapy (IGRT)[4]. These MVCT images allow the physician to monitor daily changes in target and OAR volumes. They also can be used for dose calculations to verify the delivered dose and generate adaptive radiotherapy (ART)[5-6].

The tomotherapy system has software called planned adaptive, which uses MVCT images for dose calculations in order to verify dose distribution in the anatomy at that time[7]. Some studies reported the verified dose from MVCT images and compared it with the planning dose from kilovoltage computed tomography (kVCT) images in order to evaluate the dose difference and decide on adapting treatment plans based on MVCT images.

The image value-to-density table (IVDT), which is essential for dose calculation, shows the relationship between the CT number and electron or mass density. The IVDT difference is given from various physical interaction proba-bilities in the MVCT and kVCT beams[8]. This difference affects the comparison of calculated dose results by planned adaptive software between MVCT and kVCT images. The physician may make the wrong decision by using an adaptive plan, resulting in either a false positive or false negative. The purpose of this study was to assess the efficiency of planned adaptive software by comparing between the planned adaptive calculated dose on MVCT images and the HT planning dose on kVCT images.

Material and methods

Patients

Fourteen HNC patients (median age, 51 years; range, 24-66 years) were treated between November 2011 and May 2012 with helical tomotherapy. Patient characteristics are shown in Table 1. This study was approved by the Research Ethics Committee, Faculty of Medicine, Chiang Mai University, with the study code; RAD-2556-01677 and certificate of approval No. 281/2013.

IVDT acquisition

The IVDT of MVCT images was performed on the TomoTherapy machine (TomoTherapy Hi-Art 4.2.1) with a cheese phantom, which is a cylindrical virtual waterTM phantom (TomoTherapy, Inc.) that has several holes containing density plugs. This phantom was scanned with physical densities of between 0.29 to 1.823 g/cm^3, which amounted to 12 density plugs in total. These scanned images were transferred to a TomoTherapy treatment planning system in order to measure the average Hounsfield unit (HU) values of each density plug. The relationship table between HU values and physical densities was created. The IVDT of MVCT and kVCT images is shown in Figure 1. This process was also carried out with the kVCT in order to generate another IVDT.

Acquisition of kVCT and MVCT images

All of the patients were fixed in supine position with their bodily section from head, neck and shoulders immobilized using a thermoplastic mask. The first day of kVCT scanning was performed on a spiral CT simulator (Toshiba Asteion TSX-021A), with a slice thickness of 3 mm. The field-of-view (FOV) diameter was 40 cm,

Table 1. Characteristics of head and neck patients in this study

Patient No.	Sex	Age (years)	Disease	Staging
1	M	66	Nasal cavity	T1N2Mx
2	F	46	NPC	T4N2bM0
3	F	46	NPC	T4N2bM0
4	M	52	NPC	T2N1M0
5	F	49	NPC	T2N2Mx
6	F	55	NPC	T1N2Mx
7	M	24	NPC	T2N2Mx
8	M	65	NPC	T3N1M0
9	M	56	NPC	T4N2Mx
10	M	43	NPC	T2N0M0
11	F	57	NPC	T3N1Mx
12	F	51	NPC	T3N2Mx
13	M	51	NPC	T1N2Mx
14	M	49	NPC	T1N2Mx

M; male, F; female, NPC; nasopharyngeal cancer with a matrix size of 512×512 pixels. MVCT images were acquired on the first day by using a coarse slice thickness (6 mm) on the TomoTherapy unit in the same position and with immobilization. The energy of the MVCT beam was 3.5 MV, and the FOV diameter was 40 cm, with a 512×512 matrix size.

Treatment planning and dose calculation

The kVCT images of the patients were transferred to a contouring workstation (Oncentra master plan 3.1), where the target volumes and normal organs were contoured. The target volumes were planning target volumes (PTVs), which had 5 mm margins added to clinical target volumes (CTVs), and the effect of the geometrical variations was then considered in order to ensure that the prescribed dose was absorbed into the CTVs. The PTVs were PTV70, PTV59.4 and PTV54. The PTV70 was the primary tumor and lymph nodes involved, as shown in clinical information and endoscopic and radiologic examinations. The PTV59.4 was the high risk regions, and the PTV54 was the low neck and supraclavicular node regions. The kVCT images with contours were transferred to a helical tomotherapy treatment planning system (TomoTherapy planning station Hi-Art 4.2.1) in order to generate treatment plans.

On the first day of treatment, the MVCT images were scanned, sent to planned adaptive software, and integrated into the helical tomotherapy planning system. Initially, the physicist combined the MVCT images with a kVCT image study set. This process was performed with automatic image registration by translating x, y and z and roll dimension. The kVCT images were acquired with a slice thickness of 3 mm, and MVCT scanning was obtained with coarse slice thickness (6 mm) in order to reduce the imaging dose to patients. Interpolation of the MVCT image set was required to maintain a uniformed 3 mm slice thickness, due to different scanning thicknesses. Then, the kVCT structure set was superimposed automatically on the MVCT image set to create what is called merged images. The dose was calculated on the merged images by applying the sinogram from planning kVCT.

Dosimetric parameters and statistical analyses

Dose-volume histograms (DVH) of kVCT and MVCT images for each plan were calculated for target volumes and normal structures in order to investigate the dose difference of the two-image set in dosimetric results. The dosimetric parameters of target volumes were dosed at 95% of the organ of interest (D95). The parameters of right and left parotid glands were dosed at 50% of the organ of interest (D50) and those of the spinal cord at 2% of the organ of interest (D2). All data were analyzed by Pearson's correlation, which was performed using SPSS (Statistical Package for the Social Sciences) statistics software (IBM Corp. version 17.0). The correlation was considered statistically significant at a *p*-value < 0.05, which indicates that the two datasets can be substituted by each other.

Results

Figure 2 shows the comparison of DVHs between the dose calculation performed on MVCT images, which is a verification dose

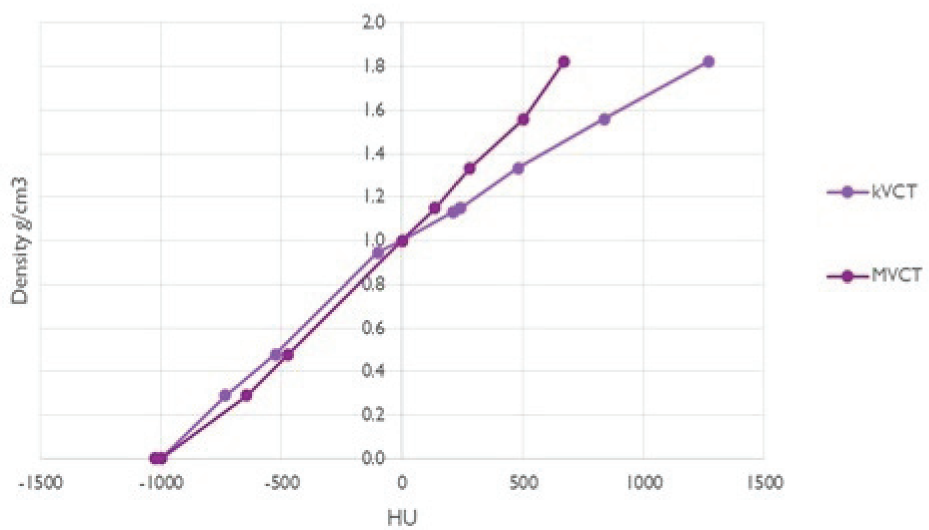

Figure 1. Image of Value-to-Density curve of MVCT and kVCT images.

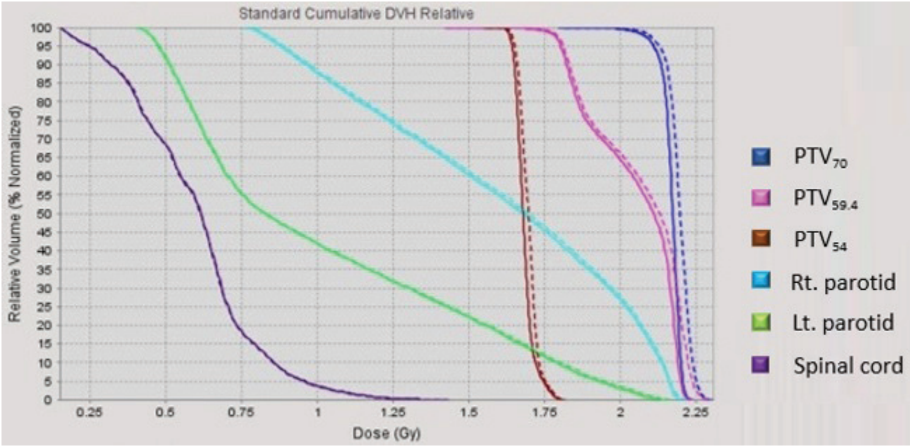

Figure 2. Cumulative dose-volumes histogram of MVCT (dash line) and kVCT (solid line) image dose calculations.

Table 2. Dosimetric comparison of the planned adaptive (MVCT) and HT planning (kVCT) dose calculation

Dosimetric parameters (n=14)	kVCT (cGy/fraction)	MVCT (cGy/fraction)	r	*p* value
D95 - PTV70	212.1±0.01	215.8±0.03	0.24	0.41
D95 - PTV59.4	179.9±0.01	183.3±0.03	0.42	0.14
D95 - PTV54	164.9±0.02	162.9±0.05	0.81	<0.05
D50 - Right parotid	89.6±0.31	91.0±0.31	0.99	<0.05
D50 - Left parotid	85.9±0.26	87.1±0.27	0.99	<0.05
D2 - Spinal cord	96.1±0.10	98.0±0.11	0.98	<0.05

kVCT; the kVCT was imaged on the first day, MVCT; the MVCT was imaged on the first day, D95; dose at 95% of organ of interest, D50; dose at 50% of organ of interest, D2; dose at 2% of organ of interest and r is a correlation coefficient, which varies in value between -1 and 1, and value 1 means perfect correlation.

(dash line), and kVCT images, which is the planning dose (solid line) for patient No.4. This study found an excellent correlation between the verification and planning dose in the right and left parotid and spinal cord. Good agreement in PTV54 and a small difference in PTV70 and PTV59.4 were found. The dose difference of both target volumes was less than 2%, which was due to a small discrepancy in kVCT and MVCT registration.

The dosimetric results of the two-dose calculation are presented in Table 2. The average D95 (cGy/fraction) of kVCT and MVCT two-dose calculation for PTV70, PTV59.4 and PTV54 was 212.1, 215.8 (p =0.41) and 179.9, and 183.3 (p =0.14), 164.9 and 162.9 (p <0.05), respectively. The average D50 (cGy/fraction) of kVCT and MVCT two-dose calculation for right and left parotid glands was 89.6 and 91.0 (p <0.05), and 85.9 and 87.1 (p <0.05), respectively. The average D2 (cGy/fraction) of kVCT and MVCT two-dose calculation for the spinal cord was 96.1 and 98.0 (p <0.05), respectively.

Discussion

Table 2 shows the verification dose from calculated MVCT images, when compared to the planning kVCT dose, and it correlates well with the correlation coefficient (r) approaching a value of 1, and significantly correlates to D95 of PTV54, D50 of the right and left parotid and

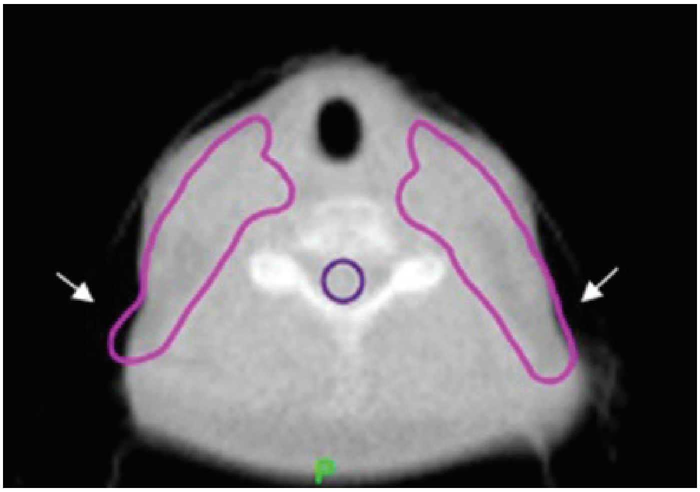

Figure 3. The part of PTV that exceeds the skin and enters the air section.

Table 3. Dosimetric results of the calculation on kVCT images, MVCT 1P day images and MVCT 1st fraction images

Dosimetric parameters (N=14)	kVCT (cGy/fraction)	MVCT 1st day (cGy/fraction)	% Diff (1st day)	MVCT 1st Fraction (cGy/fraction)	% Diff (1st fraction)
D95 - PTV70	212.1±0.01	215.8±0.03	1.74	215.6±0.03	1.65
D95 - PTV59.4	179.9±0.01	183.3±0.03	1.89	182.7±0.03	1.56
D95 - PTV54	164.9±0.02	162.9±0.05	2.61	166.7±0.04	1.09
D50 - Right parotid	89.6±0.31	91.0±0.31	1.40	86.9±0.31	1.16
D50 - Left parotid	85.9±0.26	87.1±0.27	1.56	90.9±0.27	1.45
D2 - Spinal cord	96.1±0.10	98.0±0.11	1.98	96.1±0.10	0.00

kVCT; the kVCT was imaged on the first day, MVCT 1st Day; the MVCT was imaged on the first day and MVCT 1st fraction; the MVCT was imaged on the 1st treatment day, D95; dose at 95% of organ of interest, D50; dose at 50% of organ of interest, D2; dose at 2% of organ of interest.

D2 of the spinal cord. This result indicates that the two datasets can be substituted by each other. A slight difference in D95 of PTV70 and PTV 59.4 was observe, as a result of disparity in the registration process. Some parts of PTV exceed the skin and enter the air section (Figure 3), resulting in insufficient soft tissue buildup for dose calculation. The study of Schirm *et al* on the comparison of dosimetric results between MVCT and kVCT images, with planned adaptive software in 4 patients (lung, prostate, nasal cavity and brain), found that the dose difference in PTV of the nasal cavity patient was almost 9%, due to a portion of PTV in air[9]. To solve this problem, the dose with MVCT images of the 1st treatment fraction must be recalculated. In that case, these registrations were approved by a treating physician, and this study found that the dose differences were decreased. The dosimetric results are shown in Table 3. The average dose differences in all parameters were less than 2%. These discrepancies occur, due to the difference of the IVDT calibration curve, as in the study of Langen *et al*, which reported an acceptable range of dosimetric uncertainties because variations in the calibration curve were 3%.

According to the study of Shah *et al*[10], the MVCT imaging dose for patients was 0.3, 1 and 3 cGy/day for coarse (6 mm), normal (4 mm) and fine (2 mm) slice thickness, respectively. Hence, this study acquired MVCT images with a coarse slice thickness in order to reduce the dose for the patient. However, this affected the image quality for image combination in the registration process. In addition, there was a blurring effect, which may affect the dose calculation, as in the study of Schirm *et al*. Therefore, this study suggested that MVCT images in planned adaptive calculation should use a fine or normal slice thickness.

Conclusion

The results of dose calculations on MVCT images with planned adaptive software correlate to those on planning kVCT. This indicates that planned adaptive software is useful for evaluating the dose delivery of patients, and it can be used to decide on adaptive plans. Although some case studies had a small deviation, it can be reduced by a treating physician approving the registration. Furthermore, the dose calculation will be performed with less slice thickness in each treatment fraction in order to investigate the appropriate one for adaptive plans.

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การเปรียบเทียบปริมาณรังสีที่คำนวณด้วยโปรแกรมแพลนอะแดปทีฟกับโปรแกรมวางแผนรังสีรักษาของเครื่องฉายรังสีตัดขวางแบบเกลียวหมุน

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วัตถุประสงค์ เพื่อเปรียบเทียบผลการคำนวณปริมาณรังสีบนภาพรังสีตัดขวางระดับศักย์ไฟฟ้าเมกะโวลต์ (MVCT) ด้วยโปรแกรมแพลนอะแดปทีฟ กับปริมาณรังสีตามแผนรังสีรักษาที่ใช้ภาพรังสีตัดขวางระดับศักย์ไฟฟ้ากิโลโวลต์ (kVCT) ของเครื่องฉายรังสีตัดขวางแบบเกลียวหมุน

วิธีการ ผู้ป่วยมะเร็งศีรษะและลำคอ 14 ราย ที่ฉายรังสีด้วยเครื่องฉายรังสีตัดขวางแบบเกลียวหมุน แต่ละรายวางแผนรังสีรักษาบนภาพรังสี kVCT และคำนวณปริมาณรังสีที่ PTV70, PTV59.4 และ PTV54 ผู้ป่วยทุกรายถ่ายภาพรังสีตัดขวาง MVCT ด้วยเครื่องฉายรังสีตัดขวางแบบเกลียวหมุน นำภาพรังสีตัดขวางทั้งสองมาซ้อนทับกันเพื่อคัดลอกโครงร่างรอยโรค ต่อมน้ำลายทั้งสองข้างและไขสันหลัง คำนวณปริมาณรังสีด้วยโปรแกรมแพลนอะแดปทีฟ โดยใช้ภาพรังสี MVCT จากนั้นเปรียบเทียบปริมาณรังสีคณิตที่ปริมาตรเป้าหมาย และอวัยวะสำคัญข้างเคียงด้วยวิธีสถิติสหสัมพันธ์แบบเพียร์สัน

ผลการศึกษา ปริมาณรังสีเฉลี่ยที่อวัยวะเป้าหมายร้อยละ 95 ได้รับ (D95) ของ kVCT และ MVCT สำหรับ PTV70, PTV59.4 และ PTV54 คือ 212.1, 179.9, 164.9 และ 215.8, 183.3, 162.9 เซนติเกรย์ ตามลำดับ ปริมาณรังสีเฉลี่ยที่ปริมาตรร้อยละ 50 ของต่อมน้ำลายข้างขวาและซ้ายได้รับ (D50) สำหรับ kVCT และ MVCT คือ 89.6, 91.0 และ 85.9, 87.1 เซนติเกรย์ ตามลำดับ ปริมาณรังสีเฉลี่ยที่ปริมาตรร้อยละ 2 ของไขสันหลังได้รับ (D2) สำหรับ kVCT และ MVCT คือ 96.1 และ 98.0 เซนติเกรย์ ตามลำดับ

สรุปผลการวิจัย ผลการศึกษาพบว่าปริมาณรังสีที่ได้จากการคำนวณบนภาพรังสี MVCT ด้วยโปรแกรมแพลนอะแดปทีฟ มีความสัมพันธ์อย่างมีนัยสำคัญทางสถิติกับปริมาณรังสีที่ได้จากการวางแผนรังสีตัดขวางแบบเกลียวหมุนบนภาพรังสี kVCT และสามารถใช้แทนกันได้ **เชียงใหม่เวชสาร 2558;54(1):9-15.**

คำสำคัญ: เทคนิครังสีตัดขวางแบบเกลียวหมุน โปรแกรมแพลนอะแดปทีฟ MVCT ปริมาณเชิงรังสีคณิต