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Impact of different CT slice thickness on clinical target volume for intensity modulated radiation therapy : A phantom study

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Siripachot P, Asavametha N, Oonsiri S. Impact of different CT slice thickness on clinical target volume for intensity modulated radiation therapy : A phantom study. Chula Med J 2011 Jul - Aug; 55(4): 327 - 39

Purpose : *To assess the accuracy of target volume with different computed tomography (CT) slice thickness-interval and the impact of different CT slice thickness on intensity modulated radiation (IMRT) treatment planning.*

Objectives : *To correlate the different CT slice thickness/interval with the variation of target volume on IMRT planning.*

Design : *Experimental study*

Setting : *Department of Radiology, Faculty of Medicine, Chulalongkorn University.*

Materials and Methods : *The IMRT thorax phantom (30 cm wide, 30 cm long and 20 cm thick), containing a tissue equivalent rod (2.5 cm diameter and 16 cm long) underwent CT scan with five different slice thickness/ interval (1.25 mm/1.25 mm, 2.5 mm/2.5 mm, 3.75 mm/3.75 mm, 5mm/5mm and 3.75 mm/1.25 mm). The target volume (tissue*

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rod) was outlined on all scans by two observers. The computed volumes for each CT dataset were compared with the known true volume. IMRT planning was performed on all five CT datasets. The field size and dose-volume histogram (DVH) were compared.

Results : *The difference of percentage volume between calculated and true volume of the tissue rod with CT slice thickness/interval 1.25/1.25 mm and 3.75/1.25 mm was less than 1%, whereas the 5/5 mm slice thickness/interval was 4.5%. The differences in the accuracy of the target volume among each CT slice thickness/ interval were small. However, the target volume was most accuracy on 1.25/1.25 mm and 3.75/1.25 mm slice thickness/ interval, respectively. Similar finding was seen by both observers. The differences in volume were caused by partial volume effect. The differences in field size of IMRT planning were small. However, the field size in measurements of Y axis was always larger on 1.25/1.25 mm and 3.75/1.25 mm CT scan, about 0.3 cm compared to other series. The DVH of each CT dataset was not different in term of the percentage of relative volume.*

Conclusion : *Accuracy of target volume delineation depended on CT slice thickness/interval. Target volume was most accurate on the 1.25/1.25 mm and 3.75/1.25 mm slice thickness/interval, respectively. Differences in contour volume may be due to partial volume effect. Different CT slice thickness had a small effect on field size in y axis and DVH of IMRT planning.*

Keywords : *CT slice thickness, CT slice interval, target volume, intensity modulated radiation therapy.*

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เหตุผลของการทำวิจัย : *เพื่อศึกษาความสัมพันธ์ของความหนาภาพตัดเอ็กซเรย์คอมพิวเตอร์ที่ต่างกัน และการเปลี่ยนแปลงปริมาตรเป้าหมายทางการวางแผนการฉายรังสีแบบปรับความเข้ม*

สถานที่ทำการศึกษา : *ภาควิชารังสีวิทยา คณะแพทยศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย*

รูปแบบการวิจัย : *การวิจัยเชิงทดลอง*

วิธีการ : *ศึกษาในหุ่นจำลองรูปทรวงอกสำหรับการฉายแสงแบบปรับความเข้ม (ขนาด 30 x 30 x 20 เซนติเมตร) ภายในบรรจุแท่งรูปทรงกระบอกที่มีความหนาแน่นเท่ากับเนื้อเยื่อปกติ (ขนาด 2.5 x 16 เซนติเมตร) นำหุ่นจำลองมาเอ็กซเรย์คอมพิวเตอร์จากเครื่องจำลองการฉายรังสี (CT simulator) ทั้งหมด 5 ชุด โดยมีความหนา/ช่วงระหว่างภาพเอ็กซเรย์คอมพิวเตอร์ที่ต่างกัน ได้แก่ 1.25/1.25, 2.5/2.5, 3.75/3.75, 5/5, 3.75/1.25 มิลลิเมตร ตามลำดับ ปริมาตรเป้าหมาย (แท่งเนื้อเยื่อรูปทรงกระบอก) จะถูกวาดขอบเขตขึ้นโดยผู้สังเกตการณ์ 2 คน เมื่อได้รูปร่างของปริมาตรเป้าหมายแล้วนำมาคำนวณปริมาตรของเป้าหมายในแต่ละชุด เก็บข้อมูลที่ได้นำมาเปรียบเทียบกับปริมาตรจริงของแท่งจำลอง นำภาพเอ็กซเรย์ทั้ง 5 ชุดมาแผนการฉายแสงแบบปรับความเข้ม เปรียบเทียบขนาดของลำรังสี (field size) และลักษณะกราฟแสดงความสัมพันธ์ระหว่างปริมาณรังสีและปริมาตรที่ได้รับรังสี (dose-volume histogram)*

ผลการทดลอง : *เปอร์เซ็นต์ของความแตกต่างระว่างปริมาตรที่คำนวณได้ และปริมาตรจริงของแท่งเนื้อเยื่อทรงกระบอก เมื่อใช้ความหนา/ช่วงระหว่างภาพเอ็กซเรย์คอมพิวเตอร์ 1.25/1.25 และ 3.75/1.25 มิลลิเมตร น้อยกว่า 1 เปอร์เซ็นต์ ในขณะที่เมื่อใช้ความหนา/ช่วงระหว่างภาพเอ็กซเรย์คอมพิวเตอร์ 5/5 มิลลิเมตรเป็น 4.5 เปอร์เซ็นต์ ความแตกต่างในความแม่นยำของปริมาตรเป้าหมายเมื่อใช้ความหนา/ช่วงระหว่างภาพเอ็กซเรย์คอมพิวเตอร์ต่างกันพบน้อย แต่อย่างไรก็ตาม ปริมาตรเป้าหมายแม่นยำที่สุดเมื่อใช้ความหนา/ช่วงระหว่างภาพเอ็กซเรย์*

คอมพิวเตอร์ 1.25/1.25 และ 3.75/1.25 มิลลิเมตร ตามลำดับ ซึ่งได้ผลคล้ายคลึงกันในผู้สังเกตการณ์ทั้ง 2 คน ความแตกต่างในปริมาตรเกิดขึ้นจาก partial volume effect ความแตกต่างในขนาดของลำรังสีและการวางแผนฉายแสงแบบปรับความเข้มพบน้อย แต่อย่างไรก็ตามขนาดของลำรังสีเมื่อวัดในแนวแกนวายจะยาวกว่าเสมอเมื่อใช้ความหนา/ช่วงระหว่างภาพเอ็กซเรย์คอมพิวเตอร์ 1.25/1.25 และ 3.75/1.25 มิลลิเมตร กราฟแสดงความสัมพันธ์ระหว่างปริมาณรังสีและปริมาตรที่ได้รับรังสี (dose-volume histogram) แต่ละชุดของภาพเอ็กซเรย์คอมพิวเตอร์ไม่แตกต่างกันเมื่อพิจารณาในรูปของร้อยละปริมาตรสัมพัทธ์ (percentage relative volume)

สรุปผล : *ความแม่นยำของปริมาตรเป้าหมายที่ถูกวาดกำหนดขอบเขตขึ้นกับความหนา/ช่วงระหว่างภาพเอ็กซเรย์คอมพิวเตอร์ ปริมาตรเป้าหมายแม่นยำที่สุดเมื่อใช้ความหนา/ช่วงระหว่างภาพเอ็กซเรย์คอมพิวเตอร์ 1.25/1.25 และ 3.75/1.25 มิลลิเมตร ความแตกต่างในปริมาตรอาจเกิดขึ้นจาก partial volume effect ความหนา/ช่วงระหว่างภาพเอ็กซเรย์คอมพิวเตอร์ที่ต่างกันมีผลน้อยต่อการวางแผนการฉายแสงแบบปรับความเข้ม*

คำสำคัญ : *ความหนาภาพตัดเอ็กซเรย์คอมพิวเตอร์, ปริมาตรเป้าหมาย, การฉายแสงแบบปรับความเข้ม.*

It is well known that treating the full target disease while avoiding the surrounding normal tissue is the aim of radiotherapy. Experimental and clinical evidence shows that a small change in dose of 7% to 15% can reduce local tumor control significantly and increase of normal tissue complications.[1, 2] Volume definition is important for 3D-treatment planning and for accurate dose calculation. The current development in IMRT demands precise definition of the target organ. The proper estimation of tumor volume is essential to avoid tumor remission[3]. Accurate volume definition may provide a useful measure for tumor bulk and analysis of treatment response in the future.

Although magnetic resonance imaging (MRI) has been shown to decrease inter-observer variation, although still distorted target margin. Computed tomography (CT) remains an imaging modality for dose calculation process in treatment planning. Slice thickness and slice interval between CT sections impact target volume and dose volume histogram (DVH).[4]

The Photon Treatment Planning Collaborative Work Group (PTPCWG, 1991) recommended that accurate definition of the inferior and superior borders of the target volume required a close spacing between sections. Moreover, contiguous CT slices with a thickness in the range of 3 to 5 mm for the head and 5 to 10 mm for the body should be used to achieve a reasonable compromise between resolution and throughput. PTPCWG suggested that further study would be required for optimization of CT slice thickness used in radiotherapy. [5]

At King Chulalongkorn Memorial Hospital (KCMH), the technique of CT simulator, particularly slice thickness and slice interval is individually performed among patients. The CT slices as thin as 1-2 mm as allow a more accurate reconstruction of the target volume, with a more time procedure, whereas slice thickness of 5-10 mm would be faster but it is too approximate for volume reconstruction.

The aim of this experimental study was to correlate the different CT slice thickness/interval with the variation of target volume and to study the impact of this variation in IMRT planning. The result of the study could aid radiation oncologists in selecting the optimal slice thickness in a cost-benefit perspective.

Materials and Methods

To compare the different imaging techniques with different CT slice thickness, we used an IMRT thorax phantom with, a 30-cm wide, 30-cm long and 20-cm thick, containing a tissue equivalent epoxy material rod (2.5 cm in diameter and 16 cm long) (Figure 1). The phantom was scanned with 5 different techniques. The slice thickness and slice interval are listed in Table1. The remaining parameters were kept constant in all the acquisitions as Table 2.[6]

The CT datasets were transferred to the Varian Eclipse treatment planning system (TPS) version 8.6.10 through DICOM network. The target volume (tissue equivalent rod) and the external body contour were delineated using the free-hand tool by two different observers (a radiation oncologist and a radiation oncology resident). The maximum dimensions in the horizontal and longitudinal dimension as well as the isocenter were recorded. The volume of tissue equivalent rod was computed for the five contoured dataset. A simplified version of the sum-of-polygons technique was the algorithm

used to determine target volume. It was calculated as the sum of the target area on each slice. The computed volumes for each CT dataset were recorded and compared with the known true volume value of a tissue equivalent rod.

a.

b.

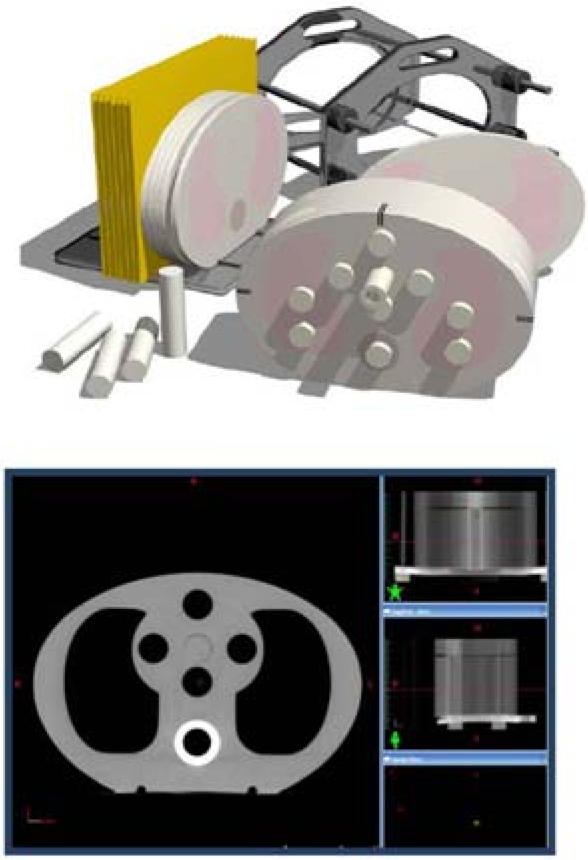

Figure 1. a: IMRT thorax phantom with, a 30-cm wide, 30-cm long and 20-cm thick, containing a tissue equivalent epoxy material rod (2.5 cm in diameter and 16 cm long)

b: The axial CT simulator scan image of IMRT thorax phantom

Table 1. The five combinations of CT slice thickness and interval to generate target volume.

Technique	**Slice thickness (mm)**	**Slice interval (mm)**
A	1.25	1.25
B	2.5	2.5
C	3.75	3.75
D	5	5
E	3.75	1.25

Table 2. Protocol for CT simulation [6]

Parameters for CT simulation	
Entry	head first
Position	supine
Scan type	helical
Tilt	0 degree
SFOV	Large
KV	120
mA	440
Rotation speed	1 sec
DFOV	35 cm (phantom diameter30 x 30 x 20)
Matrix	512

IMRT planning was performed on all five CT datasets with multileaf collimator (MLC) size 0.5 cm and 1 cm. The parameters like the number of beams, direction of beams and dose-volume constraint were kept constant in all the acquisitions. Calculation of the field size and the dose-volume histogram (DVH) for each contoured CT datasets were recorded and compared.

Statistical analysis

Measurements variation of target volume was compared using the percentage volume difference between calculated and true values of the tissue equivalent rod.

$$\text{Percentage volume difference} = \frac{\text{True volume of tissue rod} - \text{Calculated contour volume}}{\text{True volume of tissue rod}} \times 100$$

$$\text{True volume of tissue rod} = 78.5\ \text{cm}^3$$

A comparative analysis of the percentage volume difference using two observers was performed. In order to assess impact of different CT slice thickness/interval for IMRT planning, a comparative analysis of field size and DVH was conducted.

Results

Impact of CT slice thickness/interval on target volume

The horizontal maximum dimension and longitudinal dimension of the contoured rod are shown in Table 3.

As shown in Table 3, horizontal maximum dimension had a small difference in each CT slice thickness/interval, as compared with the 2.5 cm true horizontal dimension. The longitudinal maximum dimension was most accurate when used 3.75/1.25 and 1.25/1.25 mm slice thickness/interval, while it was less accurate when using 2.5/2.5, 3.75/3.75 and

Table 3. The horizontal maximum dimension and longitudinal dimension of the contoured rod for each CT slice thickness/interval. True horizontal and longitudinal dimension of rod are 2.5 cm and 16 cm, respectively.

Technique (thickness/interval)	**Horizontal Max. dimension (cm)**		**Longitudinal Max. dimension (cm)**	
	Observer 1	**Observer 2**	**Observer 1**	**Observe 2**
A (1.25/1.25)	2.6	2.6	16.01	16.01
B (2.5/2.5)	2.6	2.6	15.75	15.75
C (3.75/3.75)	2.6	2.6	15.75	15.75
D (5/5)	2.5	2.5	15.5	15.5
E (3.75/1.25)	2.6	2.6	16	16

5/5 mm, respectively. Similar finding was seen for both observers.

The percentage differences between calculated and true volume are shown in Table 4. Calculated volumes were generally smaller than true volumes. The maximum percentage of variation in target volume was observed when using in the 5 mm slice thickness/interval. The maximum percentage of variation for 5 mm slice thickness/interval was 4.5%. The percentage of variation in target volume was small when using the 1.25/1.25 mm and 3.75/1.25 mm slice thickness/interval, respectively, both were less than 1%. The differences in accuracy of target volume each datasets were small. Similar finding was seen for both observers. Although the target volumes outlined by observer 1 were more accurate than the ones outlined by observer 2 and this was noted with all CT acquisition (inter-observer variability). However, the inter-observer variability was very small (Figure 2).

Table 4. The calculated volume of the contoured rod and the percentage volume different for each CT slice thickness/interval. The true volume of contour rod is 78.5 cm^3.

Technique (thickness/interval)	**Calculated volume (cm^3)**		**Percentage volume different (%)**	
	Observer 1	**Observer 2**	**Observer 1**	**Observe 2**
A (1.25/1.25)	78.41	78.32	0.11%	0.22%
B (2.5/2.5)	76.44	76.32	2.62%	2.77%
C (3.75/3.75)	76.35	76.25	2.73%	2.86%
D (5/5)	74.91	74.86	4.57%	4.6%
E (3.75/1.25)	78.38	78.23	0.15%	0.34%

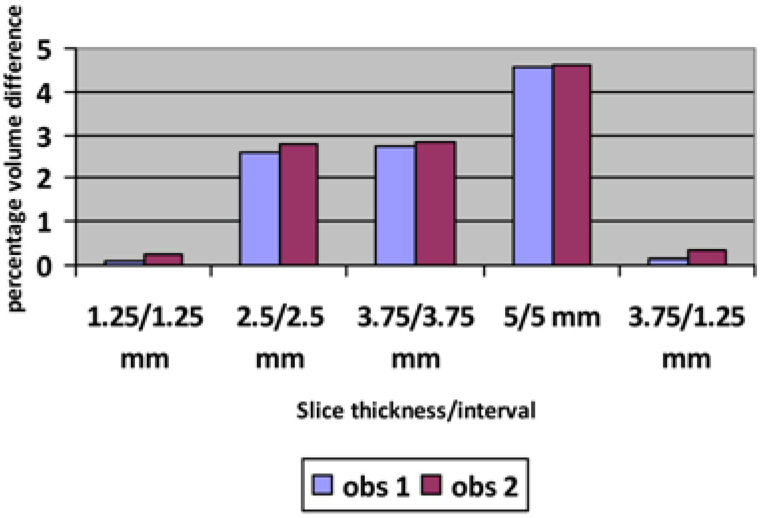

Figure 2. The histogram shows the percentage volume difference of CT slice thickness/interval 1.25/1.25 mm, 2.5/2.5 mm, 3.75/3.75 mm, 5/5 mm and 3.75/1.25 mm. The minimum percentage of variation in target volume is the 1.25/1.25 mm and 3.75/1.25 mm slice thickness/interval. The maximum percentage of variation in target volume is the 5 mm slice thickness/interval. The inter-observer variability was very small.

Impact of CT slice thickness/interval in IMRT planning

Because of the target volumes outlined by observer 1 were more accurate than the ones outlined by observer 2 in all CT datasets, so we used volume outlined by observer 1 for treatment planning with IMRT. The results of the field size in IMRT planning using 0.5 cm and 1 cm MLC are presented in table 5. The field sizes in X axis were similar among CT datasets, while there was some different field size in Y axis. The field sizes in Y axis were larger in 1.25/1.25 mm and 3.75/1.25 mm slice thickness/interval, that was consistent with the larger maximum longitudinal dimension of both techniques. Similar finding was seen in both sizes of MLC.

Table 5. Automatic field size of IMRT planning along the X axis and Y axis when using 0.5 cm MLC and 1 cm MLC.

Technique (thickness/interval)	Field size 0.5 cm MLC		Field size 1 cm MLC	
	X (cm)	Y (cm)	X (cm)	Y (cm)
A (1.25/1.25)	5	17.3	5	17.3
B (2.5/2.5)	5	17	5	17
C (3.75/3.75)	5	17	5	17
D (5/5)	5	17	5	17
E (3.75/1.25)	5	17.3	5	17.3

Figure 3 and 4 show the comparative cumulative DVH for targeted volume (contoured rod). They show the DVHs for IMRT plans planned on the 1.25/1.25 mm, 2.5/2.5 mm, 3.75/3.75 mm, 5/5 mm and 3.75/1.25 mm slice thickness/interval. The DVH data in term of ratio of total target volume (%) was not different in each CT acquisition (Figure 3). However, the comparative DVH in term of absolute target volume (cm^3) was slightly different of each CT datasets (Figure 4). The target volume was more under-dosed with 5/5 mm, 3.75/3.75 mm and 2.5/2.5 mm slice thickness/interval, respectively. In the 1.25/1.25 mm and 3.75/1.25 mm, DVH in term of absolute target volume were not different.

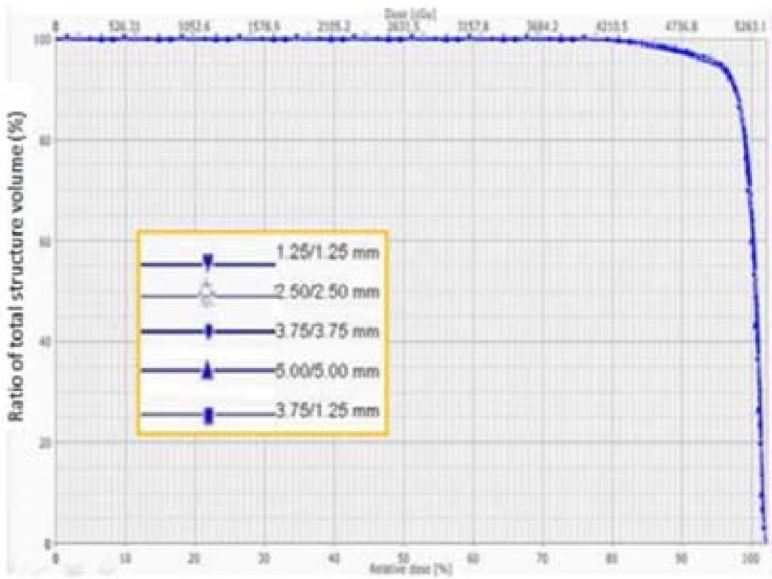

Figure 3. Shows the cumulative DVH for targeted volume in term of percentage ratio of total target volume (relative volume). Targeted volume or structure volume was a contoured rod volume.

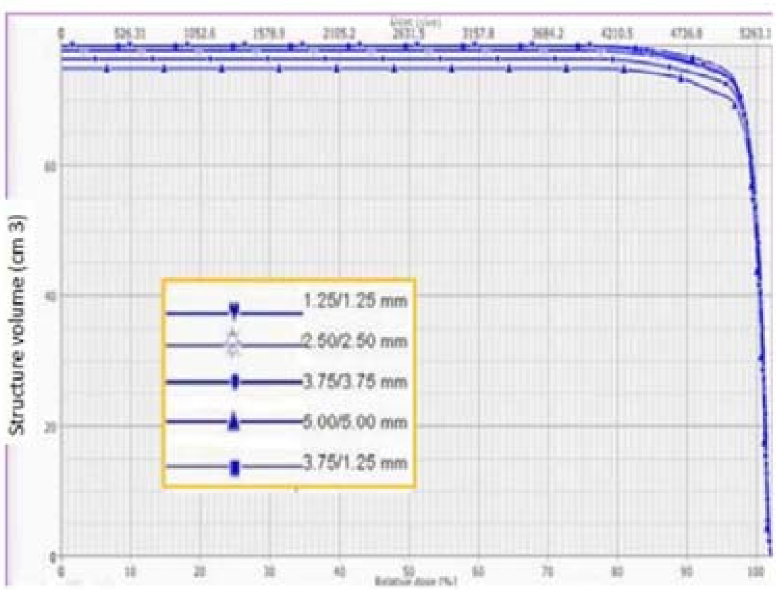

Figure 4. Shows the cumulative DVH for targeted volume in term of absolute targeted volume (cm^3). Targeted volume or structure volume was a contoured rod volume.

Discussion

The current advancement in IMRT and dose escalation requires accurate definition of the tumor volume, and tumor volume has become a critical deciding factor for efficient treatment planning. The option of imaging modality has also been investigated extensively such as magnetic resonance imaging (MRI). However CT remains a broadly used modality for external beam radiation therapy (EBRT) because most treatment planning systems depend on CT numbers for the dose calculation process. The slice thickness and interval are one of the important parameter that contributes to the fault in target delineation. Smaller slice thickness/interval has the possibility of capturing more volume of a target organ, whereas larger slice thickness/interval may miss the volume at the caudal and the cephalic end of the tumor volume. An analysis on the volume variation for different slice thickness/interval will enable radiotherapists to select the required slice thickness/ interval for radiotherapy treatment planning.

Regarding the accuracy of target volume in treatment planning, it is reasonable to acquire the smaller available CT interval. However, the time spent for manual contouring and for isodose calculation increases with the number of acquired images.

This study demonstrated that the different CT slice thickness and interval affected to the variation of target volume. Percentage of volume difference with CT slice thickness/interval 1.25/1.25 mm and 3.75/ 1.25 mm was less than 1%, whereas the 5/5 mm slice thickness/interval was 4.5%. The contoured target volume was most accurate on the 1.25/1.25 mm and 3.75/1.25 mm slice thickness/interval scan, respectively. The differences in contoured volume may be due to partial volume effect. Therefore, the smaller slice interval allows more accurate contoured volume, which corresponds to the previous study.[4, 8] Plewes et al.[8] reviewed that the small round lesion would show decreased radiographic contrast when compared to the cylindrical lesion. So the small round lesion was more difficult to detect than the cylindrical of the same diameter and material. In our experimental phantom study, we observed that the variation in the rod volume is mainly due to partial volume effect and the CT slice thickness/interval used for treatment planning. Brethelet et al. [4] studied the impact of 3 mm and 5 mm on prostate, bladder and rectum volume and concluded that 3 mm scan showed slightly larger bladder volume and difference was due to partial volume effect. In our study, the smaller slice interval (1.25/1.25 mm, 3.75/1.25 mm) showed larger and more accurate target volume, that was consistent with the larger maximum longitudinal dimension due to partial volume effect.

Partial volume effect is an important CT artifact. Berthelet et al [4] reviewed that a CT number was generated base on the tissue densities in that voxel. So the details of each organ may be lost because an average CT number for each voxel. Furthermore, partial volume effect influenced the capability of distinguishing the organ from the adjacent tissues. If the shape of organ did not change significantly in the direction of the scan, the CT number at the border of the organ will not be changed significantly. In contrast, if the shape of the organ rapidly altered in the direction of scan, the CT numbers at the border will be changed due to the partial volume effect.[10-13] In this experimental study, It is necessary to keep in mind that contouring the image of a known

and regularly shape is a much easier and more reliable procedure than performed in clinical practice, where the target are not well defined and irregular. Moreover the experimental situation is optimal image contrast that makes the target identification even easier. In clinical practice, low contrast enhancement is a problem in identifying the margin and may be caused more impact on target volume, field size and DVH of IMRT. This study revealed that the different CT slice thickness/interval had a small effect to field size and DVH of IMRT planning, due to a small variation of target volume among each CT slice thickness.

Conclusion

Accuracy of target volume delineation depends on CT slice thickness/interval. It is reasonable to acquire CT images with the smallest interval available. In this experimental study, target volume was most accurate when using the 1.25/1.25 mm and 3.75/1.25 mm slice thickness/interval, as confirmed by the two observers. Differences in the contour volume may be due to partial volume effect. Different CT slice thickness had a small effect on the field size in y axis and the DVH on IMRT planning, due to a small variation of the target volume among each CT slice thickness. However, this remains a topic for future investigations.

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