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Influence of beam pitch and tube current on lung nodule 64- MDCT - chest protocol : A phantom study

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Background : *Multi-Detector Computed Tomography (MDCT) is a powerful modality to detect small pulmonary nodules while the benefits of CT exceed the harmful effects of radiation exposure in patients; thus, CT doses should be kept as low as reasonably achievable. The way to reduce radiation dose is based on modification of scanning parameters.*

Objective : *The purpose of this study is to investigate the radiation dose and image quality affected by beam pitch and tube current for chest CT scan using a lung man phantom with lung nodules.*

Designs : *Experimental study (in vitro).*

Setting : *Department of Radiology, King Chulalongkorn Memorial hospital, Bangkok.*

Material and Method : *A lung man chest phantom with various simulated nodules was scanned by 64-MDCT with standard and high beam pitch technique and varying tube current (40-300 mA). The quantitative image quality was investigated by the Contrast to Noise Ratio (CNR). The qualitative image quality was assessed by two reviewers, using five -point scale for nodules detectability. The volume CT dose index ($CTDI_{vol}$) were recorded to evaluate the radiation dose for standard beam pitch technique and high beam pitch technique of lung nodules CT scan.*

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Results : *When the tube current, mA, was reduced from 300 to 40, the $CTDI_{vol}$ decreased from 12.3 to 1.60 mGy for standard beam pitch technique and from 8.60 to 1.18 for high beam pitch technique. Also, comparing the standard beam pitch technique and high beam pitch technique on various tube current (mA), the average radiation dose reduced by 30%. The average CNR decreased when high beam pitch was used. The scoring on image quality by two reviewers was in good agreement.*

Conclusions : *Beam pitch and tube current is an important factor for CT chest image quality. The high beam pitch CT showed a low radiation dose and short scan time when compared to the standard beam pitch with diagnostic image quality maintained.*

Keywords : *Chest scan, beam pitch, 64-MDCT.*

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ฉัตรนภา นันตื้อ, อัญชลี กฤษณจินดา. อิทธิพลของค่าบีมพิตช์และกระแสหลอดต่อก้อนเนื้อในปอด สำหรับโปรโตคอลทรวงอกด้วยเอกซเรย์คอมพิวเตอร์ 64 หัววัด: การศึกษาในหุ่นจำลอง. จุฬาลงกรณ์เวชสาร 2559 พ.ย. – ธ.ค.;60(6): 617 – 28

เหตุผลการทำวิจัย : *เครื่องเอกซเรย์คอมพิวเตอร์ชนิดหลายหัววัดเป็นเครื่องมือที่มีบทบาทในการตรวจพบก้อนเนื้อขนาดเล็กในปอด ในขณะที่ประโยชน์ที่ได้รับจากการตรวจด้วยเครื่อง เอกซเรย์คอมพิวเตอร์มีค่ามากกว่าปริมาณรังสีที่ผู้ป่วยได้รับ ดังนั้นปริมาณรังสีที่ป่วยได้รับควรเป็นไปตามหลักสากลโดยใช้ปริมาณรังสีน้อยที่สุดและเกิดประโยชน์สูงสุด วิธีลดปริมาณรังสีขึ้นกับการปรับเปลี่ยนพารามิเตอร์ของการตรวจ*

วัตถุประสงค์ : *เพื่อประเมินปริมาณรังสี และคุณภาพของภาพ เมื่อเปลี่ยนค่ากระแสหลอดและค่าบีมพิตช์ของเครื่องเอกซเรย์คอมพิวเตอร์ในการตรวจช่องอก โดยใช้หุ่นจำลองส่วนช่องอกและก้อนเนื้อในปอด*

รูปแบบการวิจัย : *การศึกษาเชิงทดลอง (นอกกาย)*

สถานที่ทำการศึกษา : *ฝ่ายรังสีวิทยา โรงพยาบาลจุฬาลงกรณ์ สภากาชาดไทย*

วิธีการศึกษา : *ทำการสแกนหุ่นจำลองส่วนช่องอกพร้อมทั้งก้อนเนื้อในปอดโดยเครื่องเอกซเรย์คอมพิวเตอร์ 64 หัววัด ด้วยค่าบีมพิตช์มาตรฐานและค่าบีมพิตช์สูงขึ้น และทำการตั้งค่ากระแสหลอด ตั้งแต่ 40 ถึง 300 มิลลิแอมแปร์ ประเมินคุณภาพของภาพเชิงปริมาณโดยการหาอัตราส่วนระหว่างความคมชัดและสัญญาณรบกวนคุณภาพของภาพ ในเชิงคุณภาพประเมินโดยผู้ประเมิน 2 คนที่มีประสบการณ์ โดยใช้เกณฑ์การประเมินการตรวจพบก้อนเนื้อในปอดด้วยคะแนน 1- 5 และบันทึกค่าปริมาณรังสีเชิงปริมาตรซีทีดีไอวอลลุ่ม (มิลลิเกรย์) ที่อ่านได้จากหน้าจอสำหรับค่าบีมพิตช์มาตรฐานและค่าบีมพิตช์ที่สูงขึ้นของการตรวจสแกนส่วนช่องอกและก้อนเนื้อในปอด*

ผลการศึกษา : *เมื่อลดค่ากระแสหลอดจาก 300 ถึง 40 มิลลิแอมแปร์ มีผลทำให้ค่าปริมาณรังสีเชิงปริมาตรซีทีดีไอวอลลุ่ม ลดลงจาก 12.3 เป็น 1.60 มิลลิเกรย์ สำหรับค่าบีมพิตช์มาตรฐาน และลดลงจาก 8.60 เป็น 1.18 มิลลิเกรย์ สำหรับค่าบีมพิตช์ที่สูงขึ้น และเมื่อเปรียบเทียบระหว่างค่าบีมพิตช์มาตรฐานและค่าบีมพิตช์ที่สูงขึ้น ในค่ากระแสหลอดต่าง ๆ มีผลให้ประมาณรังสีลดลงเฉลี่ยร้อยละ 30 เปอร์อัตราส่วนระหว่างความคมชัดและสัญญาณรบกวนคุณภาพของภาพมีค่าลดลงเมื่อใช้ค่าบีมพิตช์ที่สูงขึ้น คะแนนการประเมินคุณภาพของภาพโดยผู้ประเมิน 2 คนมีความสอดคล้องกันดี*

สรุป : *บีมพิตช์และกระแสหลอด เป็นพารามิเตอร์ที่มีความสำคัญต่อคุณภาพของภาพในการตรวจเอกซเรย์คอมพิวเตอร์ส่วนช่องอก ผลกระทบของค่าพิตช์ที่สูงขึ้นแสดงให้เห็นว่าปริมาณรังสี และเวลาในการสแกนลดลง เมื่อเทียบกับค่าบีมพิตช์มาตรฐานในขณะที่คุณภาพของภาพเพียงพอต่อการวินิจฉัย*

คำสำคัญ : *การตรวจเอกซเรย์คอมพิวเตอร์ช่องอก, บีมพิตช์, เครื่องเอกซเรย์คอมพิวเตอร์ชนิด 64 หัววัด.*

At present, the number of Multi-Detector Computed Tomography (MDCT) chest examination increases for clinical diagnostic especially in lung cancer, patient checked up for lung screening and patient with small solitary pulmonary nodule that required follow up regarding the size of lesion several times for malignancy investigation. [1 - 2] This is a major concern because of the associated radiation exposure is potential linked to the pathogenesis of cancer. The CT doses seem to be lower in updated reports, as the concerns for radiation and the advances in CT technology. [3] However, CT doses should be kept as low as reasonably achievable. During the last decade, CT dose reduction strategies have been realized by using various techniques such as tube voltage reduction, scan length optimization, individualization of scan protocol and utilization of automatic exposure control [4 - 6] while diagnostic capability can be maintained.

One of the important technical parameter to reduce the radiation dose is the beam pitch, the ratio between the table move per rotation time and the collimator width. The beam pitch of 1.0 facilitates an acquisition with no overlap or gap, while less than 1.0 facilitates an overlapping acquisition and higher patient dose, and greater than 1.0 facilitates a gap acquisition with low patient dose and image quality. [7] The purpose of this study is to investigate the radiation dose and image quality when various tube currents and beam pitch CT had been applied for chest scans using a lung man chest phantom with lung nodules.

Materials and Methods

Lung man chest phantom study

The study was performed at the Department of Radiology, King Chulalongkorn Memorial Hospital.The lung man chest phantom manufactured by Kyoto Kagaku Co.Ltd., Japan (Fig.1) has x-ray attenuation relatively to the human tissues. In order to mimic pulmonary lesions, various simulated nodule of spheres 3,5,8,10 and 12 mm in diameter (Fig.2) with CT number of 100 HU located in the lung field of the lung man chest phantom was scanned by 64-MDCT(Brilliance 64, Philips Health Care).

Figure 1. External (left) and internal (right) appearances of Lung man chest phantom.

Figure 2. Simulated nodule of spheres 3, 5,8,10 and 12 mm in diameter.

The reference value with the following protocol were a tube voltage of 120 kVp, tube current of 300 mA, helical scan mode, 64 × 0.625 mm detector configuration, 5 mm slice thickness, reconstruction slice thickness 1 mm on lung window with a center of -600 HU and width of 1600 HU rotation time of 0.5 sec, Scan FOV 350 mm, 350 mm scan length and standard filter. The examinations of lung man chest phantom were scanned from the apex of the lung to the lower costal margin by varying standard beam pitch (0.798) and high beam pitch (1.141) at tube current 40, 60, 80, 100, 200 and 300 mA while the other parameters were fixed. The scan time on lung man chest phantom examinations with standard and high beam pitch was 5.8 and 4.2 second respectively. In order to assess the radiation dose on lung man chest phantom, The Volume Computed Tomography Dose Index ($CTDI_{vol}$, mGy) were recorded from CT monitor.

The $CTDI_{vol}$ has been verified for the accuracy, reproducibility and reliable before collecting the data. The polymethylmethacrylate body phantom (32 cm diameter) was used. The measurement on $CTDI_{vol}$ was performed by placing a 100 mm pencil-shaped ionization chamber at the center and the peripheral positions of the body phantom at the isocenter of the CT bore by following to the IAEA Human Health No.19 protocol. [8] The $CTDI_{vol}$ displayed on CT monitor were recorded and compared with the measured values in percentage of difference.

Quantitative image quality

The image quality was determined by the Contrast to Noise Ratio (CNR) which measured by placing the 2 circular ROIs of similar area within the nodule and background at the same slice (Fig.3).

The CT number within the ROIs will be recorded in order to calculate the CNR by the following equation:

$$CNR = \frac{(CT_n - CT_{bg})}{SD_{bg}},$$

Where CT_n is the CT number of nodule, CT_{bg} is the CT number of background and SD_{bg} is standard deviation of background.

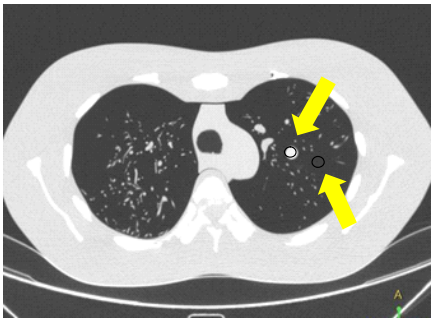

Figure 3. The location of ROIs for measuring the CT number of nodule and background.

Qualitative image quality

The image quality was assessed by two reviewers who have similar experience. They were blinded random order to the CT scanning parameter. The reviewers independently scored the image for nodule detectability on the same PACS monitor and under the same environment by using a five point scale: Score 5 = Excellent (visualize all simulated nodules with sharp edge); 4 = Good (visualize clearly 5 mm, partly visualize 3 mm in diameter of simulated nodule); 3 = Acceptable(visualize clearly 10 and 8 mm, partly visualize 5 mm in diameter of simulated nodule); 2 = Poor (visualize clearly 12 mm, partly visualize 10 mm in diameter); 1 = Unacceptable (visualize blur of all simulated pulmonary nodules).

Statistical analysis

In order to evaluate inter-observer reliability between two reviewers, weighted kappa were used for qualitative image analysis with k < 0.20, poor agreement; k = 0.20 - 0.40, fair agreement; k = 0.41-0.60, moderate agreement; k = 0.61-0.80, good agreement; and k = 0.81-1.0, almost perfect agreement. [9]

Results

For the $CTDI_{vol}$ verification, the percent difference of measured values and the monitor displayed of the polymethylmethacrylate body phantom (32 cm) were in tolerance range according to IAEA Human Health No.19. [8]

The results of the radiation dose at various tube current (mA) with standard beam pitch technique and high beam pitch technique are illustrated in Table 1. When the tube current from 300 to 40 mA resulted in the $CTDI_{vol}$ decreased from 12.3 to 1.60 mGy for standard beam pitch technique and from 8.60 to 1.18 mGy for high beam pitch technique. The study showed that the lower $CTDI_{vol}$ of high beam pitch technique than the standard beam pitch technique and the average percentage of $CTDI_{vol}$ reduction is about 30% when comparing between standard beam pitch technique and high beam pitch technique on various tube current (mA).

Table 1. Radiation exposure from different tube current (mA), beam pitch and $\%CTDI_{vol}$ reduction.

Tube current (mA)	Beam pitch	$CTDI_{vol}$(mGy)	$\%CTDI_{vol}$ reduction
40	0.798	1.60	26.25%
	1.141	1.18	
60	0.798	2.49	31.73%
	1.141	1.70	
80	0.798	3.27	29.66%
	1.141	2.30	
100	0.798	4.12	32.04%
	1.141	2.80	
200	0.798	8.18	31.54%
	1.141	5.60	
300	0.798	12.30	30.08%
	1.141	8.60	

For quantitative image quality, the bar chart representing the average CNR value obtained from all simulated nodule size plotted against with the tube current (mA) for standard beam pitch technique and high beam pitch technique is illustrated in Figure 4. It is demonstrated that the CNR decrease when beam pitch value increase because the table moves faster at higher beam pitch, thus less photon reaching the detectors. The example of measuring image for calculated CNR of tube current 60 mA compare between standard beam pitch technique and high beam pitch technique on nodule 8 mm in diameter is illustarted in Figure 5.

For qualitative image quality, Figure 6 showed the chest image for visualize of nodule detectability, for example chest image with nodule 10 mm in diameter for 300 mA with standard beam pitch (Fig. 6A), the chest image with nodule 10 mm in diameter for 300 mA with high beam pitch (Fig. 6B) and nodule 8 mm in diameter for 200 mA with high beam pitch (Fig.6C)

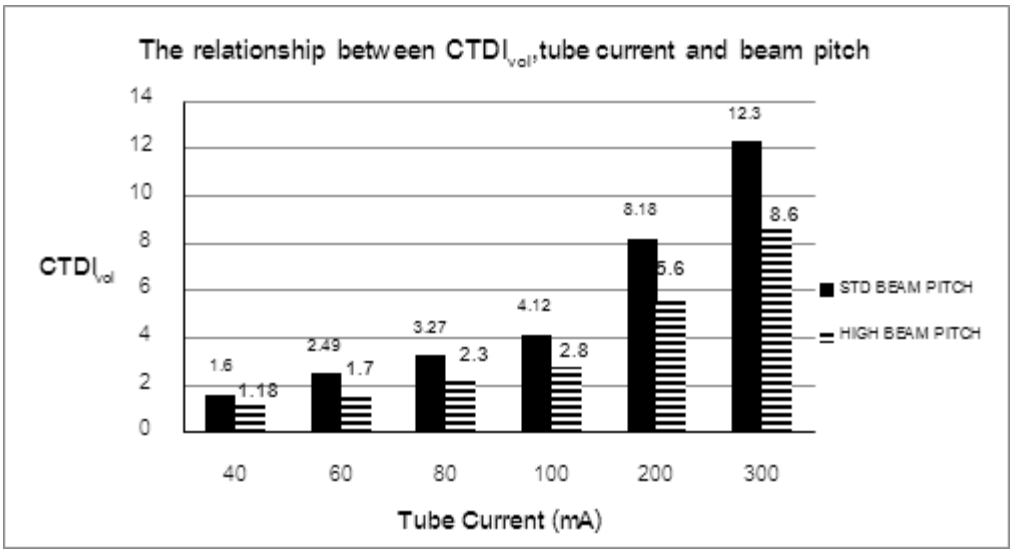

Figure 4. The relationship between CNR, tube current at different beam pitch techniques.

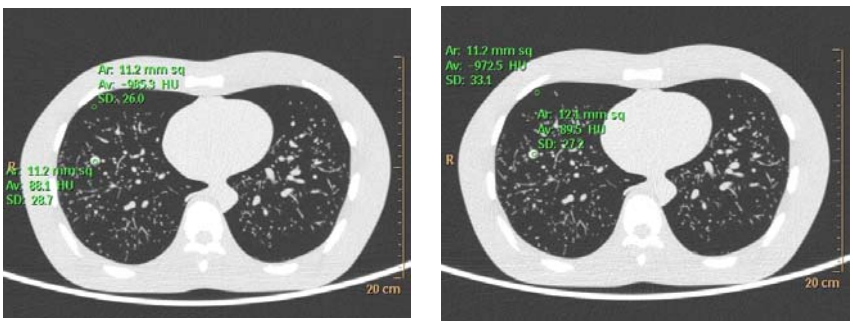

Figure 5. The measuring image for calculated CNR compare between standard beam pitch technique (left) and high beam pitch technique (right) on nodule 8 mm in diameter.

Figure 6 (A) Figure 6 (B) Figure 6 (C)

Figure 6. The example of chest image for visualize of nodule detectability.

The agreement of image quality scored by two reviewers was determined by calculating weighted Kappa of the variation tube current (mA) and beam pitch. The two reviewers had substantially inter-observer agreement for nodule detectability as illustrated in Table 2.

The k-value from weighted kappa is usually interpreted the strength of agreement, and the k-value of 0.735 is obtained from this study, which means the strength of agreement is good.

Discussion

With technological advances of computed tomography (CT), the modern MDCT provides a useful function that the user can adjust parameters to modify the image quality relate to the radiation dose.[10] One of the important parameter which affects to the image quality is beam pitch. In this study, the high beam pitch technique on Chest protocol has been applied to determine the efficiency of the radiation dose reduction and maintain image quality for the Chest protocol.

For radiation dose, the $CTDI_{vol}$ reduced around 30% when compared between high beam pitch technique and standard beam pitch technique. The $CTDI_{vol}$ of high beam pitch technique (1.141) is lower than the standard beam pitch technique (0.798) in all various tube current (mA) because in theory, increase beam pitch, which the table move fast link to the shortening total scan time and consequently affect

Table 2. The inter-observer agreement for nodule detectability by two reviewers.

Reviewer B	Reviewer A			
	Score 3	Score 4	Score 5	Total
Score 3	6	1	0	7 (58.3%)
Score 4	0	0	1	1 (8.3%)
Score 5	0	1	3	4 (33.3%)
Total	6 (50%)	2 (16.7%)	4 (33.3%)	12

**Weighted kappa k-value = 0.735*

to decrease the radiation dose which inversely proportional to the beam pitch when other parameters are held constant. [2] Moreover, this should be realized when beam pitch increases on tube current modulation technique, the tube current will automatically increase to preserve the noise conditions in the image. Thus the radiation dose does not decrease [2,11]

Yoshiharu O, *et al*[12] showed the radiation dose reduction 15% without significant deterioration of detection capability. The value was lesser approximately twice than this study even though they used higher beam pitch (0.83 and 1.48) than this study. They mentioned, if the image quality of their low dose protocol is recommended to be equal to the standard protocol, the radiation dose could be reduced to 50%. However, the CT number of nodule is -800 HU and -630 HU for image quality assessment were used in their study that difference from our study.

The average CNR value of high beam pitch technique (1.141) is lower than the standard beam pitch technique (0.798) because the high beam pitch provide high image noise due to the less photon reach the detectors. However, there is a large variation in average CNR value of small size nodules. The main variable factors result from the unstable sites of circular ROI on a very small size nodule. This is direct effect on variation of mean CT number of nodule and the standard deviation value of the background.

In clinical diagnostic, the lung nodules that have a clinical significance are non-calcified pulmonary nodule with 30 to 40 HU and ground glass opacities with -800 HU and -630 HU [12-14] which lower than the CT number of simulated nodule with 100 HU of lung man chest phantom in this study that presented the calcified nodules. This is the limitation of this study.

Although increasing beam pitch results in decreasing CNR, a small change of beam pitch still maintains the qualitative image quality. In other words, there is a little change in the intensity and contrast of the nodule. Thus it doesn't affect the nodule detectability. However, decreasing CNR owing to tube current reduction should be concerned since it could be affected the nodule detectability. [15]

The uncertainty of reviewer assessment has a little effect because the criteria for image scoring is clear and location of simulated nodule were set. The reviewers might have fatigue of the eyes. [16] However, the inter-observer agreements are substantial good even though the beam pitch is changed when scanning. This shows that our results are reproducible between the two reviewers and reliable for detection of nodule with standard beam pitch and high beam pitch technique. [9,12]

The benefit of this study is the influence of beam pitch related to the radiation dose and image quality which applied in protocol setting by the user according to the ALARA principle. Moreover, as the beam pitch increases, the scan time becomes shorter [2] which is beneficial.

Conclusions

The results of this phantom study demonstrate that beam pitch and tube current is an important factor for CT chest scan. The effect of high beam pitch CT shows lower radiation dose and shorter scan time when compared to standard beam pitch with maintaining diagnostic image quality. Selection of the proper beam pitch results in the reduction of

patient's radiation dose. Although the optimization of chest CT protocol is excluded from this study, these recommendations should be applied for valuable in chest imaging in the future.

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