Effects of the Use of Multi-Layer Filter on Radiation Exposure and the Quality of Upper Airway Radiographs Compared to the Traditional Copper Filter

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Background: *The problem of image quality in a large number of upper airway obstructed patients is the superimposition of the airway over the bone of the spine on the AP view. This problem was resolved by increasing KVp to high KVp technique and adding extra radiographic filters (copper filter) to reduce the sharpness of the bone and increase the clarity of the airway. However, this raises a concern that patients might be receiving an unnecessarily higher dose of radiation, as well as the effectiveness of the invented filter compared to the traditional filter.*

Objective: *To evaluate the level of radiation dose that patients receive with the use of multi-layer filter compared to non-filter, and to evaluate the image quality of the upper airways between using the radiographic filter(multi-layer filter) and the traditional filter (copper filter).*

Material and Method: *The attenuation curve of both filter materials was first identified. Then, both the filters were tested with Alderson Rando phantom to determine the appropriate exposure. Using the method described, a new type of filter called the multi-layer filter for imaging patients was developed. A randomized control trial was then performed to compare the effectiveness of the newly developed multi-layer filter to the copper filter. The research was conducted in patients with upper airway obstruction treated at Queen Sirikit National Institute of Child Health from October 2006 to September 2007. A total of 132 patients were divided into two groups. The experimental group used high kVp technique with multi-layer filter, while the control group used copper filter. A comparison of film interpretation between the multi-layer filter and the copper filter was made by a number of radiologists who were blinded to both to the technique and type of filter used.*

Results: *Patients had less radiation from undergoing the kVp technique with copper filter and multi-layer filter compared to the conventional technique, where no filter is used. Patients received approximately 65.5% less radiation dose using high kVp technique with multi-layer filter compared to the conventional technique, and 25.9% less than using the traditional copper filter. 45% of the radiologists who participated in this study reported that the high kVp technique with multi-layer filter was better for diagnosing stenosis, or narrowing of the upper airways. 33% reported that, both techniques were equal, while 22% reported that the traditional copper filter allowed for better details of airway obstruction. These findings showed that the multi-layered filter was comparable to the copper filter in terms of film interpretation.*

Conclusion: *Using the multi-layer filter resulted in patients receiving a lower dose of radiation, as well as similar film interpretation when compared to the traditional copper filter.*

Keywords: *Upper airway, High KV technique, Multi-layer filter, Copper filter*

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The problem with the image quality of radiographs in patients with upper airway obstructions is the superimposition of the airway over the bone of the spine on the AP view. This problem can be resolved by increasing the Kilo-voltage (kV) of X-ray energy to the high KV technique, and adding extra radiographic filters, for example copper filters, to reduce the sharpness of the bone, while maintaining clarity of the airways[1,2]. Furthermore, increasing the magnification of the image[3] allows for better detail of airway obstructions and detection of blood vessels abnormalities, such as in the detection of bronchial situs in infants and young children[4].

The principle for designing radiation filters for upper airway obstruction radiographs determines

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the absorbed radiation dose via exposure to different radiation doses in each organ type. When the energy level of X-ray is below 100 kV, the absorbed dose to the bone is more than to the tissues. When the energy level of X-ray is increased using high kV technique up to and over 110 kV, the absorbed dose to the bone and tissues will be similar. The sharpness of the bone is reduced, while maintaining clarity of the airways, making it possible to exclude tissues at different absorption levels, such as a foreign body in the upper respiratory tract overlapping the cervical spine. The radiographic image can be further improved by using the digital beam attenuator technique[5]. However, in the case when no filters are used, the problem is, despite increasing the kV with low-energy, radiation continues to emerge as a characteristic X-ray radiation. The X-ray energy cascades down several levels, making it impossible to reduce the absorbed dose to the bone, and eliminate the influence of soft radiation.

The Department of Radiology at Queen Sirikit National Institute of Child Health (QSNICH) currently uses radiation filters made from heavy metals, such as copper, to absorb low-energy radiation as much as possible, while allowing higher energy radiation to pass through. This result is a satisfactory image.

Some of the photon energy is transferred to kinetic energy by using the high kV technique. The collision of electrons from photons energy causing excitation and the subsequent dissociated energy electrons are then absorbed by the medium. However, some electrons react with the nuclei of the medium (i.e. copper), high atomic number metals and localized to Bremsstrahlung, low-energy X-ray radiation. This increases the bone absorption dose in the patients. The lower energy X-ray radiation dose can be reduced by adding lower atomic number metals than copper below the copper filter, such as aluminum (Al), to reduce the influence of lower energy from Bremsstralung. To increase the power of radiation, filters with higher atomic number metals than copper, are used such as tin for multi-layer filter. The lowest energy X-ray absorption dose from copper-layer filter and multi-layer filter is designed to improve the image quality of the upper respiratory tract and to detect better the location and cause of upper respiratory tract obstructions.

Currently, many imaging modalities are available for the detection of respiratory tract abnormalities, including plain radiographs[6], ultrasound, computed tomography, magnetic resonance imaging[7] and contrast cinetracheobronchography[8]. Some radiology departments have replaced the conventional X-ray films with computed radiography (CR), which can be used to visualize and adjusted for best image quality. This raises the question whether the improved radiographic diagnosis that combines filtration, high kV, and magnification[1] will or will not continue to be necessary. This must be considered in context of patient's exposure to radiation and which technique leads to minimal radiation exposure.

High kV/filtered airway is a non-invasive method for evaluating pediatric airways[2] and the multi-layered filter can conveniently replace the traditional copper filter. This method is, currently used at QSNICH. However, no development in the method has been made for the long time. The aim of this trial is to assess the radiation dose and the quality of the upper airway image between using the multi-layer filter we designed when comparing no-filter and the traditional copper filter.

Objective

To evaluate the level of radiation dose that patients receive with the use of multi-layer filter compared to no-filter and the traditional copper filter.

To evaluate the image quality of the upper airways between using the radiographic filter (multi-layer filter) and the traditional filter (copper filter).

Material and Method

1. Study population: Patients who underwent imaging for evaluation of upper airway obstructions at the Radiology Department, QSNICH.

2. Sample group: Patients who had upper airway X-rays taken at Radiology Department, QSNICH from October 2006 to September 2007. This study is designed as a randomized, controlled trial.

3. Radiographic imaging tools, with the use of multi-layer filter compared to no-filter and the traditional copper filter, were used in the present study.

The attenuation curve of both copper and tin were first determined. Then the filters, copper and tin, were tested with the Alderson Rando phantom to determine the exposure that is appropriate for the airway radiographic imaging. Using these data, we developed a new type of filter, called multi-layer filter.

This experimental research then studied the effectiveness of the new device that was invented for multi-layer filter examination, instead of copper filter. It was applied to the sample group. Patients were divided into two groups in this randomized, controlled trial. The experimental group was exposed to the high kVp technique with multi-layer filter, while the control group used copper filter. Film interpretation was by four

blinded radiologists (MD), who compared the images with the use of multi-layer filter and copper filter, and noted the image quality of each.

Statistical analysis

Number of samples was calculated using the formula:

$$n/group = 2\,(za+z)^2\,\frac{P\,(1-P)}{(Pt-Pc)^2}$$

$$P = \frac{(Pt-Pc)}{2}$$

Results from Rando-phantom testing

Copper filter reduced soft ray at about 40%, so we set Pc = 0.4

Multi-layer filter expected to be reduced by about 60% of the soft ray, so we set Pt = 0.6.

Sample size calculations are as follows

$$n/group = \frac{2\,(1.96+1.28)\,2\,(0.5)\,(0.5)}{(0.6-0.4)2}$$

Number of samples n = 132 cases.

This experiment is designed for 4 medical radiologists to read the films, and to score all 132 patients, contains the film X-ray by copper filter and multi-layer filter equally. Reliability of each doctor was measured by the kappa index (Measure of agreement) to confirm and ensure that all the doctors came to their diagnosis in the same way. Data analysis was done using SPSS for Windows version 10.0 and shown as percentage, mean and standard deviation.

Results

Finding the Half Value Layer (HVL) characteristics from relative attenuation curve (%) of copper and tin, experiment with the Rando phantom with the 3 levels of high kV technique, 100 kV, 120 kV and 110 kV, the HVL of copper at 120 kV is 0.2 mm, while the HVL of tin at 100 kV is 0.1 mm. The attenuation curve of copper at different levels of high kV is shown in Table 1 and Fig. 1. The attenuation curve of tin at different levels of high kV is shown in Table 2 and Fig.2.

Comparison of the level of radiation dose that patients receive for radiographs taken using the multi-layer filter, no-filter technique, and traditional copper filter

Rando's phantom found that patients who underwent the high kV technique with copper filter received less radiation dose than those who underwent the high kV technique with no filter. This was compared to the existing dose of X-rays through the Rando's phantom, which is shown in Table 3.

The amount of radiation absorbed at the surface of the Rando-phantom (tissue equivalent) from equal amounts of high kV technique with copper filter compared to the conventional technique (no-filter), by using the existing dose, showed that the radiation absorbed using the high kV technique with copper filter was about 53.45% less than no-filter. This comparison is shown in Table 4.

The amount of radiation absorbed at the surface of the Rando-phantom (tissue equivalent) from the equally high kV technique using the copper filter compared to the multi-layer filter, by using the existing dose, showed that the multi-layer filter will absorb 26% less radiation than the copper filter and will absorb

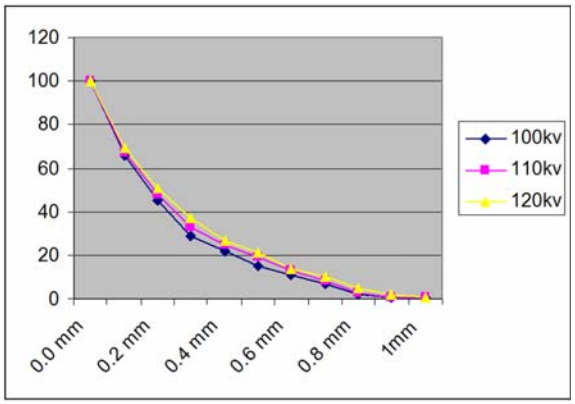

Fig. 1 Attenuation curve in copper (%).

Table 1. The attenuation in copper (%)

	Attenuation curve in copper									
	0.0 mm	0.1 mm	0.2 mm	0.3 mm	0.4 mm	0.5 mm	0.6 mm	0.7 mm	0.8 mm	0.9 mm
100 kVp	100	66	45	29	22	15*	11	7	2	1
110 kVp	100	67	48	33	25	19*	13	8	3	1
120 kVp	100	69	51*	37	27	21*	14	10	5	2

65.5% less radiation than the conventional technique (no-filter).

The amount of radiation dose that the patients received from the multi-layer filter invented was less than using no-filter and the traditional copper filter.

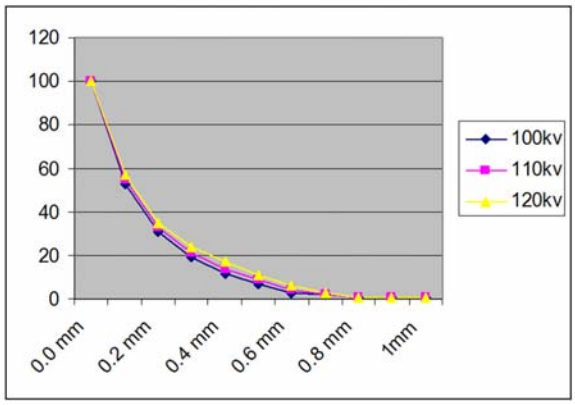

Fig. 2 Attenuation curve in tin (%).

Evaluation of radiographic image quality of upper airways taken using the multi-layer filter compared to the traditional copper filter

By using the kappa index (Measure of Agreement), which is used to compare the variability in the measurement or evaluation of the same measure or the measurement of the paired Results are shown in Table 5.

Results from the kappa index showed that the reliability between radiologist pairs were 0.901, 0.899, 0.901, 0.752, respectively, with the Approx Sig. (0.156> 0.050).

Four radiologists compared the visual interpretation from the 132 cases in the study sample X-ray film using the 2 types of filters. Results are shown in Table 6.

The percentages of 132 X-ray film using the two types of filters were reported by the radiologists; 45 % of the sample X-ray film showed multi-layer filter can diagnose stenosis or narrowing of the upper airway better than the copper filter. 33% of the sample X-ray

Table 2. The attenuation in tin (%)

	Attenuation curve in Tin									
	0.0 mm	0.1 mm	0.2 mm	0.3 mm	0.4 mm	0.5 mm	0.6 mm	0.7 mm	0.8 mm	0.9 mm
100 kVp	100	53*	31	19	12	7*	3	2	1	1
110 kVp	100	55	33	21	14	9*	4	2	1	1
120 kVp	100	57	35	24	17	11*	6	3	1	1

Table 3. Comparison between the existing doses of high kV technique with copper filter to high kV technique with conventional technique (non filter)

	High kV with Copper filter		High kV with non filter	
	I_O	I_E	I_O	I_E
1	8	5	8	2
2	8	5	8	2
3	11	8	11	4
4	11	8	11	5
5	12	9	12	6
6	12	10	12	8
7	15	12	15	9
8	15	13	15	9
9	17	14	17	11
10	17	15	17	12
	126	99	126	68

I_O-I_E = absorbed dose (by Copper filter) = 27; I_O-I_E = absorbed dose (by conventional technique) = 58

Table 4. Comparison between the existing doses of high kV technique with copper filter and high kV with multi-layer filter

	High kV with Copper filter		High kV with multi-layer filter	
	I_O	I_E	I_O	I_E
1	8	5	8	6
2	8	5	8	6
3	11	8	11	8
4	11	8	11	9
5	12	9	12	10
6	12	10	12	11
7	15	12	15	12
8	15	13	15	13
9	17	14	17	15
10	17	15	17	16
Total	126	99	126	106

I_O-I_E = absorbed dose (by Copper filter) = 27; I_O-I_E = absorbed dose (by multi-layer filter) = 20

Table 5. Measures of agreement by kappa analysis

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
The first radiologist and The second radiologists					
Measure of Agreement:	Kappa	0.901	0.067	7.119	0.000
N of Valid Cases		32			
The second radiologist and The third radiologists					
Measure of Agreement:	Kappa	0.899	0.068	7.059	0.000
N of Valid Cases		32			
The third radiologist and The fourth radiologists					
Measure of Agreement:	Kappa	0.901	0.067	7.119	0.000
N of Valid Cases		32			
The fourth radiologist and The first radiologists					
Measure of Agreement:	Kappa	0.752	0.100	6.059	0.000
N of Valid Cases		32			

Table 6. Airway X-ray film comparison between the 2 types of filter

	Frequency	%	accumulate %
Multi layer filter is better	59	44.70	45
The same quality	29	21.97	67
Copper filter is better	44	33.33	100

film showed both techniques were equal in quality and 22 % of the sample X-ray film showed the traditional copper filter was better.

Discussion

The HVL of copper at 120kV is 0.2 mm, while the HVL of tin at 100 kV is 0.1 mm. The appropriate

thickness of the copper and tin filter used for airway radiography is about 0.5 mm[1,2]. The authors found that the relative attenuation curve of tin is 7-11%, while copper is 15-21%. Therefore, the authors used tin filter for primary X-ray and added a copper filter to reduce the influence of lower energy from Bremsstralung, in case of high kV technique with the multi-layer filter.

After the comparison of the radiation dose level, Rando-phantom received radiographs taken using the multi-layer filter, no-filter technique, and traditional copper filter. The amount of radiation dose that Rando-phantom received from the multi-layer filter invented was less than using no-filter and the traditional copper filter. This indicates that the results will be the same when applied to patients.

Evaluation of radiographic image quality of upper airways taken using the multi-layer filter compared to the traditional copper filter showed that using both filters made the airway radiograph sharper. However, the aim of this research was to find the amount of radiation incidence on the surface (skin) with the Rando-phantom (tissue equivalent) using high kV technique with multi-layer filter compared with the copper filter.

Radiation dose to the patients who used high kVp technique with copper filter and multi-layer filter were less than the conventional technique of no-filter. Patients received less radiation dose using the high kVp technique with multi-layer filter compared to the copper filter and conventional technique. Film image quality for diagnosing stenosis was also comparable between the multi-layer and copper filter, as well as the conventional technique. These findings demonstrated that the multi-layer filter we invented is useful for diagnosing upper airway obstructions and there was no statistical difference when compared to the traditional copper filter.

Conclusion

Patients received less radiation dose using the invented multi-layer filter than the conventional technique and the traditional copper filter. Film interpretation results were also comparable with the traditional copper filter. The present study demonstrated that the multi-layer filter we invented is useful for the diagnosis of upper airway obstructions and that there was no statistical difference when compared to the traditional copper filter.

Potential conflicts of interest

None.

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ผลของการใช้ Multi-layer Filter ที่ประดิษฐ์ขึ้นใหม่ต่อปริมาณรังสีที่ผู้ป่วยได้รับและความคมชัดของภาพรังสีของหลอดลมส่วนต้นเปรียบเทียบกับการใช้ copper filter แบบเดิม

สมพัน กลั่นดีมา, อัญชลี เครือตราชู, ลาวัณย์ วองตาประดิษฐ์, ณรงค์ นิธิปัญญา, วรางคณา รัตนปราการ

ภูมิหลัง: จำนวนผู้ป่วยเด็กที่รับบริการการถ่ายภาพรังสีเพื่อดูความผิดปรกติของหลอดลมส่วนต้น ที่แผนกรังสีวิทยา มีจำนวนมากกว่า 300 รายต่อปี ปัญหาที่สำคัญในการเอกซเรย์ในท่าตรงจากด้านหน้า (anterior-posterior view) คือการซ้อนทับของกระดูกต้นคอกับหลอดลม ซึ่งมักจะเห็นกระดูกต้นคอชัดกว่าความผิดปรกติของหลอดลม ปัญหานี้มักได้รับการแก้ไขโดยเพิ่ม KVp และเสริมแผ่นกรองรังสี (copper filter) เพื่อลดทอนความชัดของกระดูกต้นคอลง แต่ยังคงความชัดเจนของหลอดลมเอาไว้อย่างไรก็ตาม วิธีนี้อาจมีผู้สงสัยว่าจะทำให้ผู้ป่วยได้รับปริมาณรังสีเพิ่มขึ้นโดยไม่จำเป็น และ filter ที่ประดิษฐ์ขึ้นจะช่วยให้เห็นความผิดปรกติของหลอดลมส่วนต้นได้ดีจริงหรือไม่

วัตถุประสงค์: เพื่อประเมินระดับของปริมาณรังสีที่ผู้ป่วยได้รับ ในการถ่ายภาพรังสีที่ถ่ายด้วยการใช้ multi-layer Filter เปรียบเทียบกับการไม่ใช้ filter และประเมินผลของการใช้การเพิ่มแผ่นกรองรังสี (multi-layer filter) ต่อความคมชัดของภาพรังสีของหลอดลมส่วนต้นเปรียบเทียบกับการใช้ copper filter แบบเดิม

วัสดุและวิธีการ: ทำการเก็บข้อมูล attenuation curve ของแผ่นกรองรังสีทั้งสองชนิดแล้วนำไปทดสอบกับ Alderson Rando phantom เพื่อหาค่าปริมาณรังสี (exposure) ที่เหมาะกับแผ่นกรองรังสีในแต่ละชนิด นำข้อมูลที่ได้ไปพัฒนาเป็นแผ่นกรองชนิดใหม่เรียกว่า multi-layer filter สำหรับถ่ายภาพรังสีกับผู้ป่วยจริง หลังจากนั้นทำการวิจัยเชิงทดลอง (experimental research) โดยเลือกกลุ่มตัวอย่างเป็นผู้ป่วยเด็กที่มารับบริการถ่ายภาพรังสีของหลอดลมส่วนต้นที่แผนกรังสีวิทยา ในช่วงเดือนตุลาคม พ.ศ. 2549 ถึง เดือนกันยายน พ.ศ. 2550 จำนวนทั้งสิ้น 132 ราย โดยแบ่งผู้ป่วยเป็นกลุ่มทดลองและกลุ่มควบคุมด้วยวิธีการสุ่มแบบโยนหัวโยนก้อย โดยทั้ง 2 กลุ่ม ได้รับการถ่ายภาพรังสีเอกซเรย์ด้วยการใช้ high kVp technique ซึ่งกลุ่มทดลองจะใช้แผ่นกรองชนิด multi-layer filter ในขณะที่กลุ่มควบคุมจะใช้ copper filter แล้วจึงนำภาพรังสีที่ได้ไปทำการวัดความคมชัดของภาพรังสีหลอดลมผู้ป่วย ซึ่งใช้วิธีการประเมินด้วยสายตาโดยรังสีแพทย์โดยที่ไม่ทราบว่าภาพรังสีไหนถ่ายด้วย filter ชนิดใด

ผลการศึกษา: การใช้ high kVp technique ร่วมกับ multi-layer filter จะทำให้ผู้ป่วยได้รับปริมาณรังสีน้อยกว่าการเอกซเรย์โดยไม่ใช้แผ่นกรองรังสีใดๆ อย่างมีอย่างมีนัยสำคัญทางสถิติ นั่นคือผู้ป่วยจะได้รับปริมาณรังสีลดลงประมาณ 65.5% และจากผลการอ่านภาพถ่ายรังสีพบว่า ผู้อ่านผลส่วนใหญ่เห็นว่าการใช้ high kVp technique ร่วมกับอุปกรณ์ multi-layer filter สามารถวินิจฉัยหรือเห็นการตีบแคบของระบบทางเดินหายใจส่วนต้นได้ดีกว่า 45% มีบางส่วนที่รายงานว่าทั้งสองวิธีเห็นชัดเจนเท่ากันจำนวน 33% แต่มีบางส่วนรายงานว่าการใช้ high kVp technique ร่วมกับอุปกรณ์ copper filter แบบเดิม เห็นการตีบแคบของระบบทางเดินหายใจส่วนต้นได้ดีกว่า 22% จึงเป็นการพิสูจน์ว่าการใช้ high kVp technique ร่วมกับอุปกรณ์ multi-layer filter ช่วยให้ความสามารถในการวินิจฉัยโรคได้ดีกว่าการใช้ high kVp technique ร่วมกับอุปกรณ์ copper filter แบบเดิม

สรุป: Multi-layer filter ที่ประดิษฐ์ขึ้นสามารถลดปริมาณรังสีที่ผู้ป่วยได้รับได้ดีกว่าแบบไม่ใช้ filter ใดๆ และสามารถลบการซ้อนทับของเงากระดูกที่มีผลต่อระบบทางเดินหายใจส่วนต้นได้ดีเมื่อเทียบกับการใช้ copper filter แบบเดิม