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Aluminum Equivalent Filter As an Inexpensive Alternative to the Niobium Filter in Reducing Patient Dose

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Abstract
A 50 μm thick niobium filter and its quantitatively determined aluminum equivalent filter were evaluated for effects on entrance skin dose, image quality, and x-ray tube loading for three different tube voltages in radiology. There was no significant difference in the reducion in entrance skin dose and increase in tube loading between two filters while keeping radiographic contrast on the film. For the clinical use of the aluminum equivalent filter as an alternative to the niobium filter in radiology, aluminum equivalent filter thickness at the mid energy range of radiology, 90 kVp, was measured and the filter was applied to the other kVp values, 73 and 125 kVps, to evaluate the effect on the entrance skin dose and tube loading. There was no significant difference between two filter cases at the selected kVp. The aluminum filter with equivalent thickness can be used as an inexpensive alternative to the niobium filter.

1. INTRODUCTION

One primary goal of radiology is to obtain images of the patient of sufficient quality to provide adequate diagnostic information while staying within acceptable level of patient dose. Unfortunately, the x-ray beam spectrum emitted by the anode of an x-ray tube is polychromatic and contains low- and high-energy photons. Low-energy photons have no chance of reaching the image receptor and contributing little to image formation while contributing excessively to patient dose. High-energy photons which have an advantage on patient dose are inferior in terms of producing good image contrast. Not surprisingly, therfore, the optimum is assumed to be found in the central part of the spectrum.

Since 1952, the use of a filter between the x-ray tube and patient to reduce the number of low- and high-energy photons from the beam before they reach the patient thus reducing radiation dose without losing image quality is common[1,2,3,4,5]. The first group of filter, conventional filter, uses low Z elements and particularly absorb low energy photons. Even though these filters generally absorb fewer high energy photons they effectively raise the mean energy of the beam. The second group is the K-edge filter. There is a fundamental difference in absorption curves between conventional filter and K-edge filter elements, which demonstrate a sharp increase in the absorption of photons with energies just above

the K-shell binding energy of the element. By choosing a K-edge filter appropriately, a band pass filter which
suppresses both the soft (like any conventional filter) and hard portions of the spectrum (due to additional absorption by K-shell electrons) may be approximated[6,7,8]. The essential performance characteristics, patient dose, image quality (represented by radiographic contrast), and x-ray tube loading, should be considered in choosing a filter for use in a radiographic system. The ideal filter selectively filters out the lower energy photons of the x-ray spectrum while maintaining image contrast for clinical interpretation without substantially increasing x-ray tube loading to avoid a significant decrease in x-ray tube life. All of these, however, can never be best simultaneously and therefore there should be an optimization. The optimal filter should act as a bandpass filter, absorbing both low- and high-energy photons of the x-ray spectrum.

It is suggested that two filters are quantitatively equivalent if they produce the same decrement in exposure for a specified incident x-ray spectrum. In other words, the spectra after passing through two quantitatively equivalent material (filter) layers of thickness possess equal areas although their shapes are different[9,10]. Equivalent thickness is calculated from the ratio of the linear attenuation coefficients, physical densities, and thicknesses of the two filters. Two filters are qualitatively equivalent if they transmit the same relative spectral intensity distribution for a given incident x-ray spectrum. According to this definition, it is simple to find pairs of filters that produce the same half-value layer (HVL) for a given incident spectrum[4,11].

The purpose of this study is to evaluate a niobium filter and an aluminum filter which is quantitatively equivalent to the niobium filter. To answer the question whether an aluminum equivalent filter can be used as an inexpensive alternative, the performance characteristics are examined. For the peformance characteristics, entrance skin dose, image quality, and x-ray tube loading of the aluminum filter are compared with those of the niobium filter experimentally by using a custom-made chest phantom.

2. MATERIALS AND METHODS

The x-ray unit used in this study was a Ployphos 50 (Siemens, Aktiengesellschaft, Erlangen, Germany) with a falling load generator, a rotating anode x-ray tube. Source to image distance was 183 cm (72 inches) and a reciprocating Buchy grid, 12:1, 40 lines/cm, was equipped. Filter materials in this study were aluminum, alloy 1100, and a 50 μm thick niobium filter (Rad/Red Laboratories Inc., Ontario, Canada) encased in plastic to prevent oxidation. Filters were placed on the face plate of the collimator for all measurements. Filtration from glass-walled x-ray tube and collimator was kept constant for all measurements and was referred to inherent filtration. No added filtration was used for the inherent filtration, filter position at zero-mm Al. A chest phantom which was constructed of acrylic and aluminum plates to give similar optical densities to those in radiographs of human subjects in the different regions of the chest (Kim CS and Wilson CR, presented at the 1992 Annual Meeting of the American Association of Physicists in Medicine) was used for radiographic contrast, exposure, and x-ray tube loading studies. All exposure measurements were made with an MDH exposure meter (Model 1515) with Model 10X5-6 chamber (Radcal Corp., Monrovia, CA).

The first experiment measured the equivalent thickness of aluminum to niobium filter for three different kVps. The thickness of the aluminum equivalent filter is different at different kVp setting. In this study, the thickness of aluminum equivalent to the niobum filter was determined quantitatively under the assumption that two beam spectra, after passing through the niobium filter and aluminum attenuators, had equal areas, exposures, even though the two filtered beams were different in quality, HVLs. An ionization chamber was placed 80.5 cm from the x-ray focal spot to measure the exposure. Settings for mAs were 12.5, 8, and 8 at 73, 90, and 125 kVp, respectively. Using the niobium filter, exposures were measured in the technique mode. In the phototimed mode the thickness of the aluminum attenuator was adjusted until the exposure was the same value with that of the fixed mAs at each peak voltage. The aluminum thickness of same exposure reading as that from the niobium filter was selected as the thickness of the quantitatively equivalent filter to the niobium filter for each tube voltage setting. The *in air* measurements were carried out in good-beam geometry.

1. Radiographic Contrast of Objects

Aluminum adsorbers, 3- and 6-mm thick with areas of 1 cm^2, were positioned on the entrance surface of the chest phantom which was located 150 cm from the x-ray tube. Radiographs of the phantom were taken using Kodak T-Mat C film with a Lanex-medium screen (Eastman Kodak, Rochester, NY) for three filter situations, inherent filtration, added niobium filter, and added aluminum equivalent filter, at 73, 90, and 125 kVps. All films were developed using a Kodak processor (Model M6AN RP X-OMAT). Radiographic contrast defined as the difference in optical density between the inside and surrounding areas of the aluminum absorbers was determined in the lung, mediastinum, and surrounding areas of the aluminum absorbers was determined in the lung, mediastinum, and cardiac regions of the phantom. Optical density measurements were done with a X-Rite densitometer (Model 301, X-Rite, Inc., Grandville, MI). The differences in optical densities were tested using the two-sample t-test to determine the significance of the difference in radiographic contrasts between three filter situations for three regions. A p value of less than 0.05 was used to indicate a significant difference.

2. Entrance Skin Dose

The patient dose was expressed in terms of entrance skin dose which could easily be calculated using entrance skin exposure. The exposure was measured with the ionization chamber placed 49.5 cm from the focal spot of the x-ray tube and the inverse square relation was applied to calculate the exposure on the entrance surface of the phantom.

The phantom thickness varied were from 6.7 to 13.1 cm, 11.3 to 20.1 cm, and 15.5 to 25.5 cm for 73, 90, and 125 kVp, respectively. The exposure in the phototimed mode which gave a constant film density of 1.2 above base plus fog was measured and corresponding exposure time from the chamber reading was recorded. Chamber reading of exposure was converted into absorbed dose at the entrance surface of the phantom from the backscatter factor (BSF), the exposure ratio in air to that on the surface of the phantom, and conversion factor, 8.69 mGy/R. Measured BSFs, 1.35, 1.40, and 1.41 for the inherent filter, added niobium filter, and added aluminum equivalent filter, respectively, were used in calculating skin dose at 73 kVp. Those values for 90 and 125 kVps were 1.37, 1.44, and 1.43 and 1.41, 1.45, and 1.44, respectively. Regression line between entrance skin dose and exposure time was determined for the kVp used. The reduction in entrance skin dose relative to the inherent filtration for two filler situations, added niobium and added aluminum filter with equivalent thickness, was calculated at three kVps used.

3. Tube Loading

The ionization chamber was placed 77.0 cm from the phantom to measure the exposure in the phototimed mode. With the Siemens Polyphos 50 generator the mA decreases during an exposure. Although the exposure time was indicated on the console panel, exposure. exposure in mR were used for the phototimed mode to determine mAs in the technique mode. For three different tube voltages, 73, 90, and 125 kVps, technique mAs was adjusted until the measured exposure was equal to that from the phototimed mode at each kVp. The mAs corresponding to a chamber reading of exposure in the phototimed mode could be detxermined from regression efuation relating exposure to mAs. As mAs change in the phototimed was the indicator of the change of tube loading, (tube current)·(exposure time), the change of tube loading, was defined as the ratio of mAs required for maintaining the same exposure with the added niobium filtration and with the added aluminum equivalent filtration to that with the inherent filtration only.

3. RESULTS

Aluminum equivalent thickness to a 50 μm niobium filter are calculated, Tabl 1, with quantitative approach under an assumption of monoenergetic spectrum, for three kVp settings. The difference in thickness between measuring values and those from a quantiative calculation comes from the assumption of monoenergetic beam spectrum.

Table 1. Aluminum equivalent thickness (mm) to a 50 mm thick niobium filter for three kVp settings.

kVp Used	Calculation	Measurement
73	4.66	3.57
90	4.22	3.37
1.25	2.97	3.20

1. Radiographic Contrast of Objects

The contrast change is expressed as a relative optical density difference in percentage as compared to that of the inherent filtration. The contrast changes for radiographs obtained with the three filters in three different regions of the chest phantom at 73, 90, and 125 kVp settings are shown in Figure 1. Both the niobium and aluminum equivalent filters slightly degrade image contrast comparing to that observed in the image obtained with the inherent filtration. There is, however, no statistical difference in radiographic contrast for three locations between the three filter situations at all kVps. For all selected kVps, no statistical difference in contrast reduction is found between the niobium and aluminum filters with quantitatively equivalent thickness in all three regions.

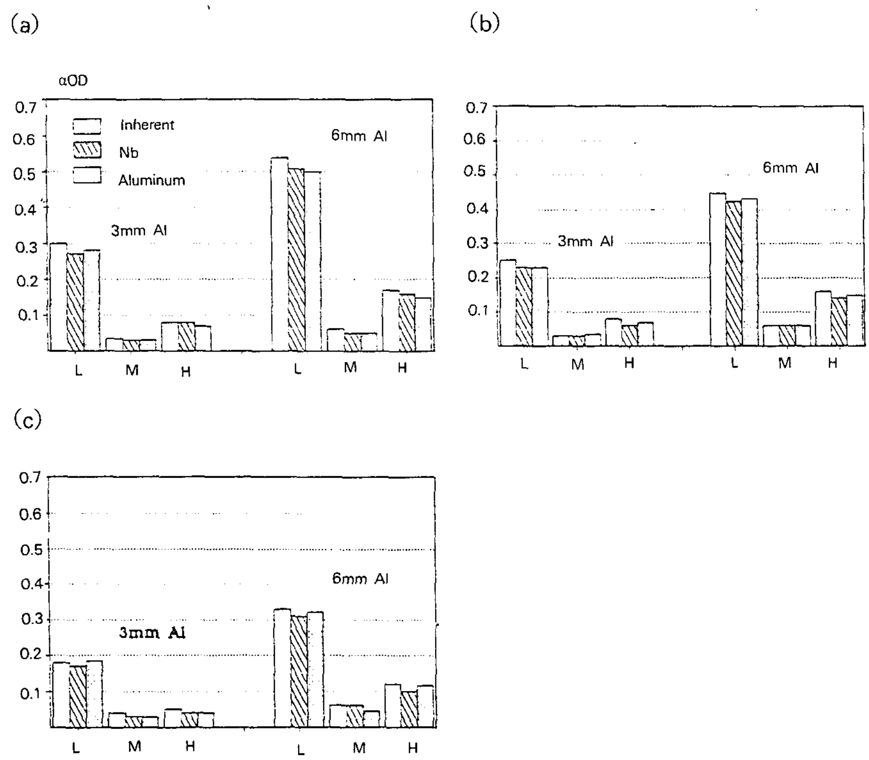


Figure 1. Change in radiographic contrast for three regions of the chest with the three fiter situations:(a) 73. kVp, (b) 90kVp, and (c) 125kVp. *d(OD)=Difference in optical densities, L=Lung, M=Mediastinum, H=Heart.*

2. Entrance Skin Dose

Reduction in entrance skin dose with the use of the niobium and aluminum equivalent filters relative to the inherent filtration are shown in Figure 2. As expected, for all filter systems, the higher the kVp, the lower the entrance skin dose due to the higher penetration of the beam. Over 73 and 125 kVp range, both the niobium and aluminum filter with equivalent thickness give 30 to 49 percent reduction of entrance skin dose over that withthe use of the inherent filtration alone.

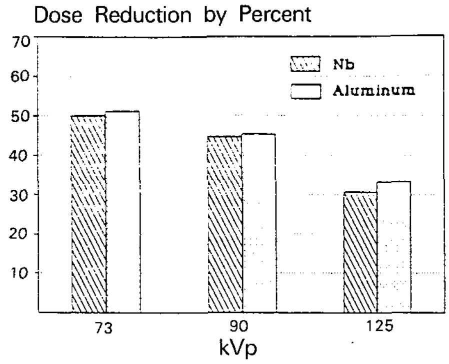


Figure 2. Reduction in entrance skin dose for two filler situations compared with the inherent filtration at several kVp settings.

3. Tube Loading

The increase in mAs for two filters shown in Figure 3 demonstrates that the niobium and aluminum equivalent filters require more tube loading than no addded filter situation by 54 to 110 percent, depending on kVp settings. This increase in tube leading is greaten at lower kVp, than at higher kVp. setting. This increase in tube leading is graten at lower kVp than at higher kVp. At 125 kVp, the niobium and aluminum equivalent filter situation require about 54 percent increase in tube loading over no added filtrations to maintain exposure and therefore optical density of the film. Increase in tube loading with the aluminum filter with equivalent thickenss is close to that with the niobium filler for kVp range used and the dfference is less than 3 percent.

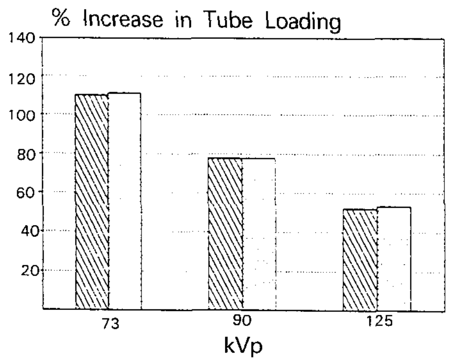


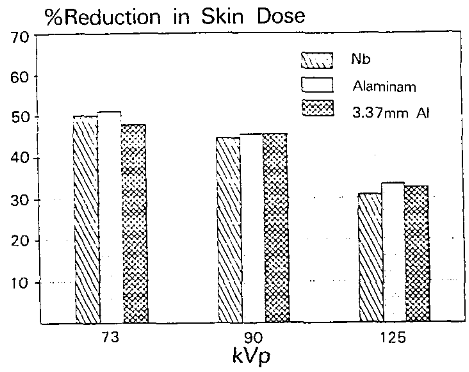
Figure 3. Increase in tube loading for the added niobium and added aluminum equivalent filter situations over the inherent filtration.

4. DISCUSSIONS

The benefit of extra filtration is the reduction of absorbed dose to the patient. This achieved by the shift in spectral distribution of the x-ray beam towards higher energies. The disadvantages of extra filtration are decrease in image contrast and the increase in tube loading which is necessary to compensate for the extra absorption of photons in the filter itself.

In practice, the benefit of reducing the absorbed dose to the patient from the use of a filter must be carefully weighted against the cost of such filter, possible decrease in image contrast, and need for additional tube loading. The entrance skin dose for the 50 μm niobium filter was significantly reduced compared with the inherent filtration only. The reduction of entrance skin dose of 30 to 49 percent is obtained by using the niobium filter over 73 to 125 kVp range. This shows that increasing radiation quality by more beam filtration reduces dose to the patient necessary for a constant optical density to the film. For the comparison between the niobium and aluminum filters, better relative dose re-

(a)



(b)

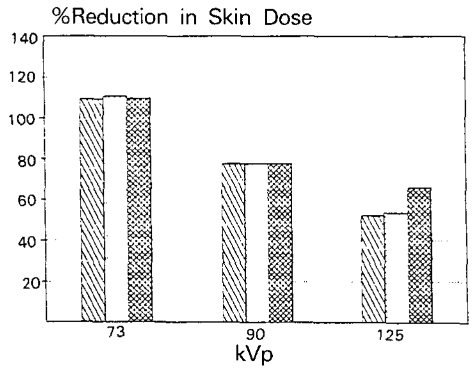


Figure 4. Change of (a) entrance skin dose and (b) tube loading with the aluminum filter. The aluminum equivalent thickness determined at 90kVp was used for 73 and 125kVp situations.

duction with aluminum filter is found. This benefit has to be paid for by an increase in tube loading by 53 to 110 percent to keep the same image quality on the film. The experimental data presented here clearly demonstrate the usefulness of the niobium filter, which is capable of significantly reducing skin dose to the patient without losing image contrast. Moreover, an aluminum filter with equivalent thickness reduces the entrance skin dose by 35 percent at 125 kVp but increase the tube loading by 55 percent, which is very close to that for the niobium filter of 53 percent. In the range of 73 to 125 kVp, this study shows that the introduction of the aluminum filter with equivalent thickness is significantly better from the point of view of the reduction of entrance skin dose.

In clincal situation, the choice of aluminum filter with different thickness for different kVp used is impractical. To investigate the possibility of the application of a quantitatively determined aluminum equivalent filter to the niobium filter in radiology, one set of experiment is performed. Aluminum equivalent thickness to the niobium filter at 90 kVp, 3.37 mm, was applied for 73 and 125 kVp to know the change of tube loading and entrance skin dose, There was no big difference between these two situations, 3.37 mm Al and aluminum equivalent thickness at 73 and 125 kVps, and the biggest change in percent increase in tube loading with 3.37 mm aluminum was 25 percent at 125 kVp and 0.065 in entrance skin dose at 73 kVp. In the range of 73 to 125 kVp, the aluminum equivalent thickness at 90kVp can be used for all kVp settings without any significant change in tube loading and entrance skin dose. However, the difference between filtration with niobium is negligible when thickness of the aluminum filter is matched to give the same attenuation of x-ray spectrum as the niobium filter. Even though the amount of scattered radiation or the spatial resolution did not evaluated quantitatively in the study, quantitatively determined aluminum equivalent filter at 90 kVp can used as an inexpensive alternative to the niobium filter in radiology.

5. CONCLUSION

An aluminum filter which is quantitaively equivalent to the niobium filter is evaluated. A comparison of performance characteristics between the niobium and aluminum equivalent filters shows that the aluminum filter with quantitavely equivalent thickness to the niobium filter is slightly better from the of point of view of patient dose reduction. No significant difference in the increase of tube loading is found between two filters while keeping radiographic contrast on the images. Concerning the radiographic image quality, no difference between the niobium and aluminum filters was observed. For the clinical use of the aluminum equivalent filter as an alternative to the niobium filter, aluminum equivalent filter thickness determined at the mid energy of radiology is applied to the other kVp values. There was no significant difference in the entrance skin dose and tube loading between two filter cases at the selected kVp. In summary, the aluminum filter with quantitatively equivalent thickness can be used as an inexpensive alternative to the niobium filter in radiology.

Acknowledgments

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6. REFERENCE

1. E.D. Trout, J.P. Kelley, and G.A. Cathey: The Use of Filters to Control Radiation Exposure to the Patient in Diagnostic Roentgenology:AJR, 67, 946−963(1952)
2. M.L. Kohn, A.W. Gooch, and W.S. Keller: Filters for Radiation Reduction: A Comparison: Radiology, 167, 225−257(1988)
3. J.E. Villagran, B.B. Hobbs, and K.W. Taylor: Reduction of Patient Exposure by Use of Heavy Elements as Radiation Filters in Diagnostic Radiology: Radiology, 127, 249−254(1978)
4. H. Thierens, M. Kunnen, A. Van der Plaetsen, and O. Segaert: Evaluation of the use of a niobium filter for patient dose reduction in chest radiography: British J. Radiol, 64, 334−340(1991)
5. P.C. Shrimpton, D.G. Jones, and B.F. Wall: The influence of tube filtration and potential on patient dose during x-ray examinations: Phys Med Biol, 33, 1205−1212(1988)
6. D.S. MacDonald-Jankowski and C.P. Lawinski:The reduction in radiation dose for intraoral radiographs by the use of thin K-edge filters: British J. Radiol., 64, 524−528(1991)
7. C.B. Burns. J.B. Renner, P. Gratale, and L.L. Moyle: Niobium/Aluminum filters Reduce Patient Exposure: Radiologic Technology, 63, 170−175(1991)
8. H.D. Nagel: Comparison of performance characteristics of conventional and K-edge filters in general diagnostic radiology: Phys Med Biol, 34, 1269−1287(1989)
9. R.G. Waggener and C.R. Wilson, eds.: Quality Assurance in Dignostic Radiology: American Institute of Physics, New York(1980), pp.105−117
10. H.D.Nagel: Aluminum equivalence of materials used in diagnostic radiology and its dependence on beam quality: Phys Med Biol, 31, 1381−1399(1986)
11. R.J. Jennings: A method for comparing beam-hardening filter materals for diagnostic radio logy: Med Phys, 15, 588−599(1988)

환자에게 주는 선량을 감소시켜주는 니오비움 필터의 대체물로서의 저렴한 알루미늄 필터

김 창선
고려대학교 의료원, 방사선종양학과

초 록

두께가 50 μm인 니오비움 필터와 정량적으로 대등하게 결정된 알루미늄 필터를 입사표면 선량, 영상의 질, X-선관에 걸리는 부하를 진단 방사선의 에너지 영역에서 평가하였다. 입사 표면 선량의 감쇠와 선관에 걸리는 부하의 증가를 비교해 볼 때 두 경우에 특이할 만한 큰 차이가 없었고 이 때 필름상의 화상의 대조도는 일정하게 유지 시켰다. 임상에서 알루미늄 필터를 니오비움 필터로 대용하기 위하여 진단 방사선의 에너지 영역의 중간 지점, 90 kVp, 에서 대등한 알루미늄 필터의 두께를 측정하였고 이 필터를 73 kVp 와 125 kVp에 적용시켜 입사 표면 선량과 X-선관에 걸리는 부하를 비교 평가하였다. 선택된 두 kVp 에서 두 필터의 경우에 특이할 만한 차이는 없었다. 니오비움과 대등한 두께의 알루미늄 필터는 니오비움 필터의 저렴한 대체물로 쓰일 수 있다.