CHARACTERIZATION OF SIEMENS FORCE CT BOWTIE FILTERS

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ABSTRACT

Purpose: To characterize the four bow tie filters (BTF) (two head and two body) on a dual-source Siemens FORCE CT scanner through non-invasive means by using a real-time dosimeter.

Methods: The Characterization of Bowtie Relative Attenuation (COBRA) method, developed by JM Boone[1] and further elaborated by BR Whiting[2], was augmented with additional beam quality measurements (HVLs). A 0.6 cc ion chamber was positioned near the periphery of the scan field of view for each of the two CT x-ray sources (Tube A and Tube B); the detector remained stationary while the tubes were separately activated and rotated around the detector; the tube collimation was open to its maximum so that the x-ray cone-beam encompassed the dosimeter throughout its rotation. Measurements were made at 80 and 120 kVp. The acquired dose-rate waveforms were distance corrected and then fitted to a polynomial equation for smoothing purposes. Additional stationary tube exposure measurements were obtained at three different fan angles in order to better characterize the quality of the x-ray beam (HVLs of Al) through different amounts of BTF material. The BTF thickness was then determined in mm of aluminum-equivalent thickness relative to the center of the filter for the four BTFs.

Results: The shapes of the bow tie filter profiles determined for the two energies had the expected shape and were in close agreement with each other (e.g., the max thickness deviation between the two profiles for the Tube B head filter was 0.20 mm). The body BTF thickness profiles for both tubes were in good agreement with published results utilizing a different method[3]; no published head BTF was available for comparison.

Conclusions: We have determined the shape and relative thickness of four BTFs (two head and two body) used in a Siemens FORCE CT scanner in units of mm of aluminum-equivalent thicknesses by incorporating measurements of HVLs at various fan beam angles with the COBRA[1] method.

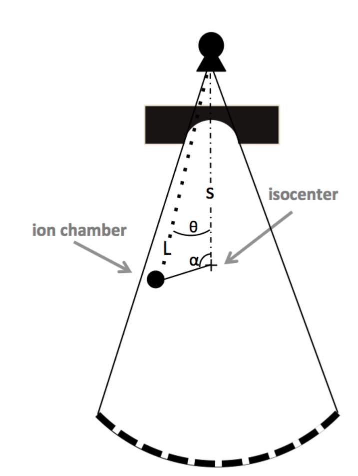
INTRODUCTION

Computed tomography (CT) scanners use a bowtie filter (BTF) to improve dose utilization by shaping the beam to better complement the shape of a patient. The BTF is thinner for the central ray and becomes incrementally thicker with increasing fan angle, thus giving the filter its characteristic bowtie shape. Some advantages to using a BTF are: reduced detector dynamic range requirements[1], reduced dose to the periphery of the patient, and reduced scatter – resulting in a better image signal-to-noise ratio[4]. Most modern CT scanners use two BTFs of different sizes: one for head and one for body imaging. Properties of BTFs such as thickness and composition are proprietary. Knowledge of these properties would allow for characterization of photon fluence and, therefore, a better estimation of the patient dose when simulating (via Monte Carlo) the scanning environment[1]. The traditional method of estimating the BTF shape requires a stationary tube and series of dosimetry measurements of the x-ray beam in the fan angle direction[5]. Such a method requires special scanner permissions to park the tube, which most sites do not have. In contrast, the "characterization of bow tie relative attenuation (COBRA)[1]" uses a real-time dosimeter to measure a dose rate waveform during a single gantry rotation. This data, when combined with source-to-detector distance corrections and HVL measurements, can be used to determine the BTF profile[1].

METHODS AND THEORY

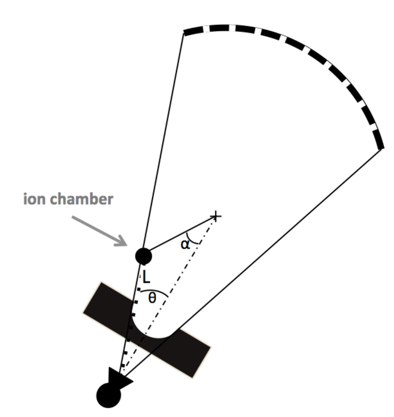
A Radcal 10X6-0.6 high dose rate ion chamber (0.6 cm^3 active volume) was connected to a Radcal Accu-Gold+ digitizer module (10 kHz sampling rate) and positioned as close to the edge of the scan field of view (SFOV) as possible in order to sample a large range of fan angles. For each tube (A & B) and each BTF (head & body) combination, an 80 kVp and 120 kVp measurement was obtained with following shared scan parameters: (1) 3 tube rotations at 0.5 sec/rot, (2) 50 mA tube current, and (3) a CT detector configuration of 96x0.6 mm (57.6 mm beam width at isocenter). Due to the diverging nature of the x-ray beam and the varying thicknesses of the BTF along each fan angle θ from source-to-detector, the dose rate measurements produced resembled a waveform. If no BTF were present, the unattenuated dose rate, $I(\alpha)$, at the location of the dosimeter would be described by

$$I(\alpha)=\frac{s^2}{L(\alpha)^2}I_0 \tag{1}$$



where s is the source-to-isocenter distance, L is the source-to-dosimeter distance, α is the angle between s and L, and I_0 is the intensity of the source. If the profile of the BTF at fan angle θ is $F(\theta)$, the dose rate recorded by the dosimeter can be described by

$$I^*(\theta,\alpha)=F(\theta)\frac{s^2}{L(\alpha)^2}I_0 \tag{2}$$



The ratio of the distance corrected measured waveform $I^*(\theta,\alpha)$ to the relative unattenuated dose rate $I(\alpha)$ yields the BTF profile. This profile can be transformed into an aluminum-equivalent thickness $T(\theta)$, Eq. (3), using a linear attenuation coefficient μ that is representative of the effective energy of a beam at a particular fan angle θ.

$$T(\theta)=-\frac{\ln\left(F(\theta)\right)}{\mu} \tag{3}$$

Current literature[5] uses the central ray HVL measurement – obtained by either measurement or manufacturer specification – as a surrogate for the effective energy of the beam. As the fan angle is increased, the filtration on the beam is increased resulting in a harder beam (i.e. higher HVL). In order to characterize the energy of the beam emerging from the BTF, we used a special service mode option that rendered the tube stationary and obtained a set of three HVL measurements along the axis orthogonal to the z-axis at fan angles {0°, 7.35°, 16.95°} and {0°, 7.35°, 14.45°} for Tubes A and B, respectively. Linear interpolation was used to determine the BTF HVL at fan angles located between the HVL measurements.

RESULTS

Figures 1a-d shows the relative (to the center) thickness of the BTF is millimeters of aluminum for Tube A (Head and Body) and Tube B (Head and Body) for both 80kVp and 120kVp acquisitions. The 80kVp and 120kVp profiles closely match each other and have the expected BTF shape. Table 1 shows the maximum calculated thickness difference between energies for each filter.

Figure 2 is a comparison of the Tube A Body BTF profile at 120kVp for the fan angles sampled with the results obtained by Yang *et al* [3] – Yang's measurements cover ~24° of fan angle and utilized linear array of detectors and a rotating tube. The maximum difference at any fan angle is 0.83 mm Al at 80kVp and 0.54 mm Al at 120kVp.

Figure 3 shows the BTF profiles calculated with energy characterization by only the central ray versus the BTF profiles calculated with energy characterization from multiple fan angle HVL measurements for Tube B Head filter at 120 kVp. Table 2 shows the maximum differences for each of the filters at the two energies.

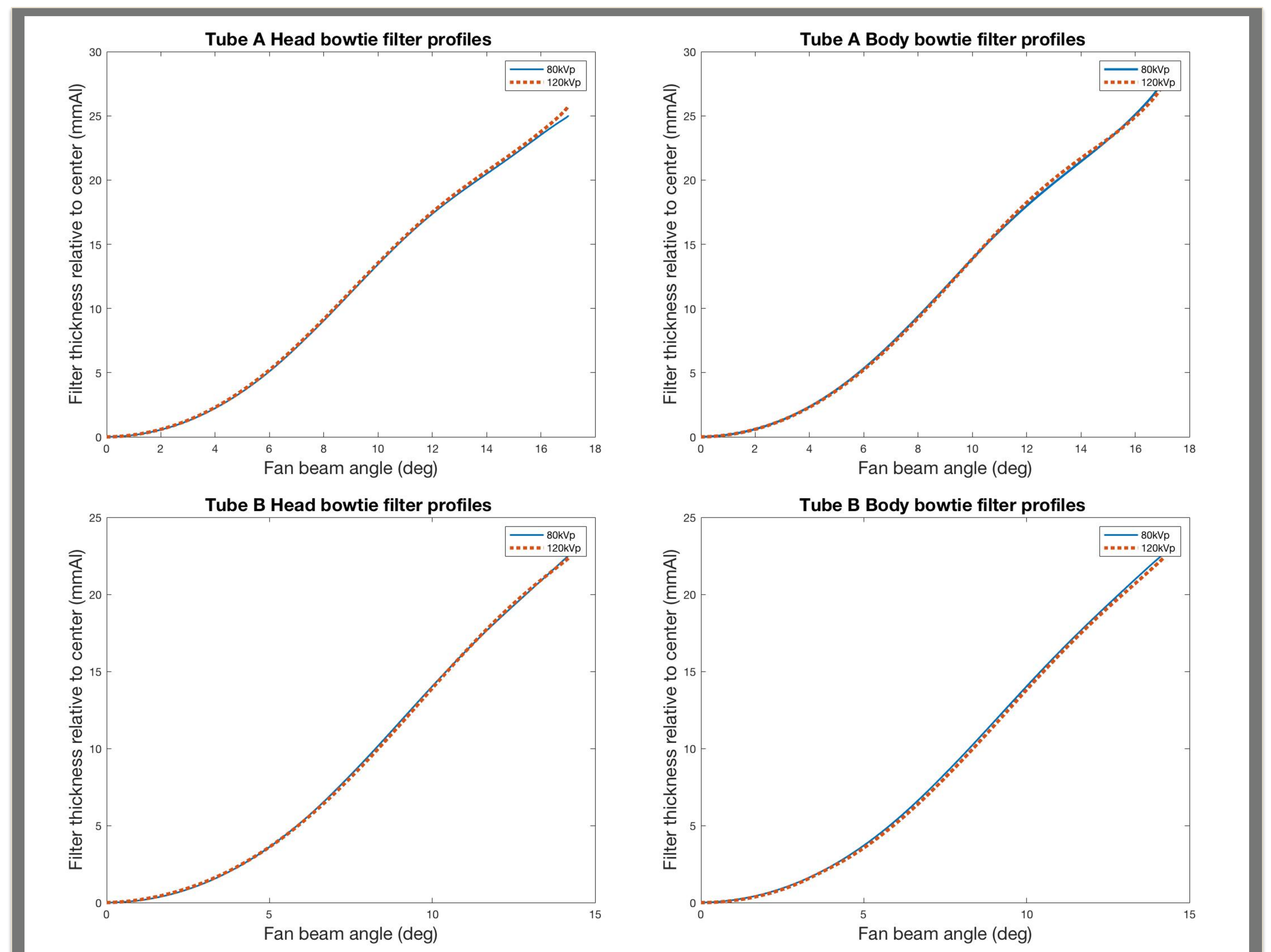


Figure 1: Calculated profile thickness relative to the center in mm Al for 80 kVp and 120 kVp acquisitions with (a) Tube A head BTF, (b) Tube A body BTF, (c) Tube B head BTF, and (d.) Tube B body BTF.

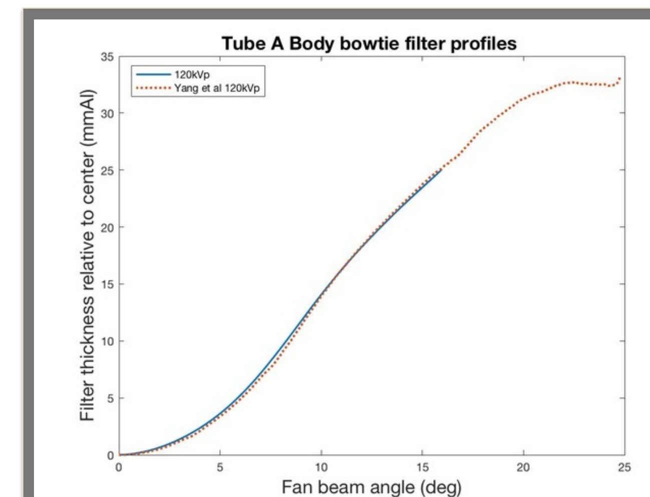


Figure 2: The results obtained in this work for Tube A Body BTF are in good agreement with the results obtained by Yang *et al.*

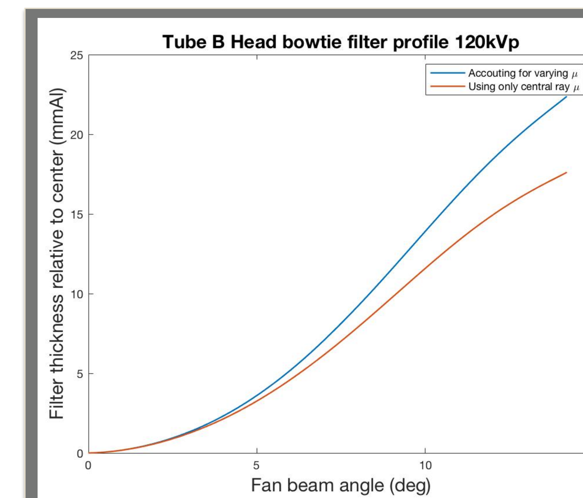


Figure 3: Using the central ray HVL measurement to characterize the energy of the beam throughout the fan angle results in an underestimation of the thickness towards the edge of the filter as seen in the Tube B Head BT filter profile.

Filter	Maximum Difference (mm)
A Head	0.84
A Body	0.64
B Head	0.20
B Body	0.33

Table 1: Maximum thickness difference in mm Al between 80 kVp and 120 kVp acquisitions.

Filter	Maximum Difference (mm)	
	80 kVp	120 kVp
A Head	6.84	6.47
A Body	6.98	6.50
B Head	5.43	4.77
B Body	5.45	4.77

Table 2: Maximum thickness difference in mm Al between multiple- and single-measurement energy characterization

CONCLUSIONS

The COBRA method + HVL measurements has been shown to produce BTF profiles in good agreement with other methods. In our study, the fan angle range investigated was restricted to a FOV occupied by an average patient. The resulting derived BTF profiles obtained at different energies (80 kVp & 120 kVp) were in close agreement with each other and with results obtained by Yang *et al* for the body BTF – no published head BTF was available for comparison.

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