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Original paper

# Method for determining the half-value layer in computed tomography scans using a real-time dosimeter: Application to dual-source dual-energy acquisition

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## ABSTRACT

*Purpose:* We have proposed a method for determining the half-value layers (HVL) in dual-source dual-energy computed tomography (DS-DECT) scans without the need for the X-ray tubes to be fixed.

*Methods:* A custom-made lead-covered case and an ionizing chamber connected with a multi-function digitizer module (a real-time dosimeter) were used. The chamber was placed in the center of the case, and aluminum or copper filters were placed in front of the aperture. The HVL was measured using aperture widths of 1.0, 2.0, and 3.0 cm for tube potentials of 80, 120, and 150 kV in single-source single-energy CT (SS-SECT) scans and was calculated from the peak air kerma rate (peak method) and the integrated air kerma rate (integrating method); the obtained values were compared with those from a conventional non-rotating method performed using the same procedure. The HVL was then measured using an aperture width of 1.0 cm for tube potential combinations of 70/Sn150 kV and 100/Sn150 kV in DS-DECT scans using the peak method.

*Results:* In the SS-SECT scans, the combination of a 1.0-cm aperture and the peak method was adequate due to the small differences in the HVL values obtained for the conventional non-rotating method. The method was also found to be applicable for the DS-DECT scans.

*Conclusions:* Our proposed method can determine the HVL in SS-SE and DS-DECT scans to a good level of accuracy without the need for the X-ray tubes to be fixed. The combination of a 1.0-cm aperture and the peak method was adequate.

## 1. Introduction

Diagnostic X-ray systems use Bremsstrahlung and characteristic radiations, which means that their beams are poly-energetic. In order to perform quality assurance tests, estimate absorbed doses in patients, and evaluate computed tomography (CT) number accuracies, we first need to determine the half-value layer (HVL). However, determining this value has not traditionally been done for CT scanners, because service engineers are needed to modify the X-ray tube that measures the HVL.

To solve this problem, previous studies have investigated several kinds of noninvasive techniques that did not require the assistance of service engineers [1–5]. These techniques can measure the HVL in CT while the CT scanner is in either a rotating exposure mode or a localizer radiograph (e.g., “Scout” or “Topogram”) mode; this was done using an integrating ionization chamber. One example of such a technique is the lead-covered case method, which can measure the HVL in CT scanners while in a rotation exposure mode, as well as provide reasonably accurate HVL measurements [5,6]. In this particular method, an ionization chamber integrates the exposure when an X-ray tube passes through the aperture of the lead-covered case.

A dual-source CT (DSCT) scanner has two separate detector arrays and two separate X-ray tubes [7]. When dual-energy CT (DECT) is performed using the DSCT scanner, low- and high-energy scans are

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obtained simultaneously. Previous papers have demonstrated the effectiveness of images generated from DS-DECT scanners [8–10]. It is also important to determine the HVL in a DS-DECT scanner, as it proves that the scanner can produce enough high-quality radiation for good-quality images to be obtained. However, noninvasive techniques cannot be used to measure HVLs in DS-DECT scanners, because the kinetic energy released per unit mass (kerma) that originates from low- and high-energy scans cannot be separated. To the best of our knowledge, no paper has proposed using a noninvasive method for determining the HVLs in DS-DECT scanners.

Recently, a real-time dosimeter that is able to measure a temporal signal (kerma rate as a function of time) has become commercially available. A time-efficient measurement of the HVL in CT scans is made possible through the use of the real-time dosimeter and an assembly of aluminum filters [11]. Because the sampling rate of the real-time dosimeter is high, a peak can be observed when an X-ray tube passes through the aperture when the dosimeter is used in the lead-covered case method; there is a possibility that, when DS-DECT is performed, two peaks, from the low- and high-energy scans, can be separately observed.

In this paper, we have proposed a method for both applying the lead-covered case method (referred to as the modified lead-covered case method) and the real-time dosimeter; this is done so that we can determine the HVL in DS-DECT scans without the need for the X-ray tubes to be fixed. We also determined how accurately single-energy single-source (SS-SE) and DS-DECT scanners measure HVLs, so that we could compare our method against a conventional “gold standard” method that uses a non-rotating exposure mode.

## 2. Materials and methods

### 2.1. CT scanner

A third-generation DSCT system (SOMATOM Force; Siemens Healthineers, Erlangen, Germany) was used. The system can perform SE and DE scans, and it has SE tube potentials from 70 to 150 kV, for every 10 kV, and DE tube potential pairs of 80/140, 70/Sn150, 80/Sn150, 90/Sn150, and 100/Sn150 kV, where Sn denotes the addition of a 0.6-mm tin filter for the high-energy beam.

### 2.2. Real-time dosimeter

Real-time dosimeter measurements were acquired using an Accu-Gold multi-function digitizer module connected to a 10X6-3CT ionization chamber (Radcal Corporation, Monrovia, CA, USA). The digitizer had a 10 kHz bandwidth and was able to record temporal waveforms (kerma rate as a function of time) by copy-pasting them to spreadsheets. In this study, the module was grounded so as to reduce noise and false triggers, and the trigger levels (i.e., sensitivity) was set to “Free,” which created a manual trigger with a start/stop function. The dosimetry information was fed into a laptop computer running “Accu-Gold” software version 1.6.3.0 (Radcal Corporation), which was used for the purposes of display and storage.

### 2.3. Lead-covered case

We prepared a custom-made lead-covered polystyrene foam case; in the center of this case, we were able to put a CT ionization chamber. The thickness of the lead plate and the size of the case were 4 mm and 30 × 30 × 15 cm, respectively [5]. The polystyrene foam around the X-ray passage between the aperture and the ionization chamber was removed to provide clearance for the X-ray passage. When the aperture located on the outer surface was completely covered by the lead plate, the exposure was undetectable at a maximum tube potential pair of 100/Sn150 kV. Two 4 mm thick lead plates with sharp cutting edges were placed on the same side of the aperture, so that we could adjust the aperture width by adjusting the position of the two plates.

### 2.4. High purity aluminum and copper filter

A set of high-purity aluminum (Al) A1050 or copper (Cu) C1100 filters were used to attenuate the X-ray beam. The size of the filters was 10 × 10 cm. The Al filters had thicknesses of 0.5, 1.0, 2.0, 3.0, and 5.0 mm. For measuring the HVL for a tube potential of Sn150 kV, we used Cu filters with thicknesses of 0.1, 0.2, 0.3, 0.5, and 1.0 mm in addition to the Al filters.

### 2.5. Modified lead-covered case method

Fig. 1 shows the experimental setup of the modified lead-covered case method that we have proposed. The case was placed on the CT table and set so that the chamber, which was in the center of the case, was located at the isocenter of the gantry. Al or Cu filters were placed 15 cm over the aperture to minimize the effect of X-rays scattered by the filters.

By using the real-time dosimeter, we were able to obtain two types of dose values, peak air kerma rate and integrating air kerma rate, from one non-helical scan. The peak air kerma rate, $\dot{K}_p$, was obtained from the temporal waveform (air kerma rate as a function of time, Fig. 2). The method using the peak air kerma rate was named the “peak method.” The integration of air kerma rate, $K$, was done as in the following equation:

$$K = \int_{t_0}^{t_{\max}} \dot{K}(t)dt \tag{1}$$

where $t_0$ represents the origin time and $t_{\max}$ represents the time it takes for the measurement to finish (Fig. 2). The method where the air kerma rate was integrated was named the “integrating method.”

After the initial $\dot{K}_p$ or $K$ were measured from one non-helical scan without the use of any filters, we performed measurements with filters while using the same parameters (i.e., adjusting the Al or Cu filters into the beam path until the resulting exposure was less than half that of the initial value). Each measurement was performed more than three times both without the filter and with each filter thickness in order to reduce the random error, and the HVL was determined from the average $\dot{K}_p$ or $K$ by using the following procedure: firstly, an approximation was derived from the relationship between the filter thickness and the average $\dot{K}_p$ or $K$; secondly, the half-value of the initial value was calculated from the approximation in order to determine the HVL by using the goal-seek feature in the what-if analysis tool of Microsoft Excel 2013 (Microsoft Corporation, Redmond, WA, USA).

In order to investigate the accuracy of both methods and determine the appropriate aperture width, the HVL in the SS-SECT was measured using aperture widths of 1.0, 2.0, and 3.0 cm for tube potentials of 80, 120, and 150 kV for both the peak and integrating methods. The obtained HVL value was compared with that obtained from the conventional non-rotating method, which is described in the next sub-section. The HVL in the DS-DECT was then measured using aperture width of 1.0 and 2.0 cm for tube potential pairs of 70/Sn150 and 100/Sn150 kV for the peak method. Before measuring the HVL in the DS-DECT, we checked that the peak air kerma rate of the 100 kV beam in the presence of Sn150 kV beam (DS-DECT) was equivalent to that in the absence of Sn150 kV beam (SS-SECT). All of the measurements were performed using the following scan conditions: a tube current of 200 mA; 1.0 s per rotation; and a detector configuration of 96 × 0.6 mm.

### 2.6. Conventional non-rotating method

Fig. 3 shows the experimental setup for the non-rotating method. By using the service-engineering mode, we were able to place the X-ray tube in the bottom of the gantry. The ionization chamber was placed 15 cm above the isocenter of the gantry, and the Al or Cu filters were