Radiation dose reduction in CBCT imaging using K-edge filtering and energy weighting

Se-Ryong Kang, Woo-Jin Lee, Sang-Yoon Woo, Dae-Seung Kim, and Won-Jin Yi

Abstract— **This paper presents K-edge filtering and energy weighting methods which enhance the contrast with less radiation does. Usually, energy weighting methods are used with photon-counting detector based CT for each energy bin data obtained to enhance the quality of image. However, we used these methods combine with K-edge filtering in energy-integrating detector. Using K-edge filtering, different energy bin data for energy weighting methods were obtained, and then energy weighting factors were calculated to enhance the contrast of image. We report an evaluation of the contrast-to-noise ratio (CNR) of reconstructed image with and without these two methods. This evaluation was proceeded with two phantoms; one is the phantom created personally, and the other is Sendentexct IQ dental CBCT (SENDENTEXCT, EU). As for the phantom created personally, the CNR of images reconstructed with these methods were increased than CNR of standard images. It was seen that 31% to 81% in each energy weighting method for optimizing each material (cortical bone, inner bone, soft tissue, iodine (18.5g/l), iodine (37g/l)). In conclusion, we can enhance the contrast of CT images with less radiation dose using K-edge filtering and energy weighting method**

I. Introduction

The use of cone-beam computed tomography (CBCT) technology in many ways has increased rapidly in recent years. Dental cone-beam computed tomography (CBCT) can rapidly provide high-resolution cross-sectional images for clinical diagnoses, and dental CBCT images with a large field of view (FOV) are used to diagnose lesions around the oral and sinus cavity. Because of these applications, dental CBCT has become a vital diagnostic tool in clinical practice [1]. Also, cone-beam computed tomography (CBCT) is now becoming a powerful tool for image-guided radiation therapy, because of the large volume CT images [2].

However, its clinical utility may be limited because of its high imaging dose to a large volume of the patient [2]. This has led to increased interest in, and concern about the radiation exposure induced by CBCT scanners [3]. Therefore, it has become the best topic in the imaging researches that getting best image quality under the smallest dose of radiation exposing to patients.

There are many possible methods to reduce radiation dose in CT. For example, CT system optimization is the one of the methods for dose-reduction strategies. It improves the dose efficiency of CT systems, which is related to many system components, including the detector, collimator and beam-shaping filter. Since range of CT scan is directly related to the total radiation dose, it is also important to keep the scan range as small as possible. Another common method to optimize radiation dose is to adjust x-ray exposure control automatically. Patient's size or weight is measured and the appropriate tube current is then determined [4].

And, also optimally designed data processing and image reconstruction methods are strategy for dose-reduction, because they can generate images with lower noise levels without sacrificing other image properties [4]. Data processing in the projection data domain prior to the image reconstruction usually takes into account photon statistics in the CT data such as smoothing the projection data by optimizing a likelihood function or using an adaptive nonlinear filter based on the statistical model [5]. Reducing noise in the images after reconstruction is also method for controlling noise in CT [4]. The image reconstruction method and data utilization are also important factors for optimal noise control. Iterative reconstruction methods have stood out for reconstruction method for radiation dose reduction such as adaptive statistical iterative reconstruction (ASIR) [6].

However, these strategies for radiation dose reduction have some limits in the technological aspect. CT system optimization methods depend on the present research and development situation of components of CT system and also need additional task and time for patient-specific CT scanning. As to image-based filtering, these methods usually changes the appearance of the CT image and sacrifices the low-contrast detect –ability [4]. The image reconstruction method can reconstruct the CT image from less than full-scan projection data, but the utilization of those redundant data is desirable in terms of reducing image noise [4, 7]. Therefore, in the light of the advantage and limits of these methods, we had developed the new methods to reduce the loss of low-contrast detect-ability of CT image and enhance the image contrast in less radiation dose by obtaining CT projection data with existing CT system in which only K-edge filter is added and applying energy weighting methods and iterative

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reconstruction methods. So that, the purpose of this study is enhancement of the contrast with less radiation does by using K-edge filtering and energy weighting methods.

II. Materials and Methods

Current commercial cone-beam CT system which uses energy integrating detector is employed in this study for scanning objects at certain tube potentials. A circular phantom which we created personally was scanned on a flat panel detector (Tomonics T80, Raymedical, Korea) at tube potential 60kVp, 0.2 mA with and without K-edge filter (Fig.1). Other phantom, Sendentexct IQ dental CBCT (SENDENTEXCT, EU), was scanned with dental CBCT (DINNOVA 3, WILLMED, KOREA) (Fig.2). The tube voltage and the current were fixed to 100kVp and 9mA, respectively.

At the phantom created personally, the images that processed with no other methods are scanned over 360° in 1.125° step. With a single scan, CT system is able to acquire up to 320 two dimensional projections. On the other hand, the images that processed with k-edge filter and energy weighting are scanned over 360° in 3.375° step. And then, 106 two dimensional projections would obtained with a single scan. In amount of radiation dose, standard data which means projection data obtained without strategies has full radiation dose. But, projection data with K-edge filtering and energy weighting method are acquired in two thirds of total radiation dose.

Iodine was chosen for this study on the basis that their K-edge would have an effect on the projection x-ray imaging. The K-edge of iodine is 33.17 KeV, and these K-edge energies would absorb the low-energy of x-ray. We used thin PMMA of which the thickness is 1mm to hold iodine. The width of the iodine filter is wide enough to cover the whole source size, and the thickness of iodine is 1mm. The designed filter is mounted in front of the source. Fig.3 shows the geometry of the proposed method and our experimental setup. The filter is placed between the X-ray source and the object. Using this K-edge filter, we obtained two different CT images.

For reducing the image noise and improvement of the CNR, the two different CT scanned images were regarded as dual-energy X-ray image data [8], and then calculated for obtaining each energy-weighting factor. The factors are proportional to the difference between the number of photons detected by a ray traveling through a background material and a ray traveling through the background material with an embedded contrast element, and inversely proportional to the noise in the projection measurement [9].

An approach for optimal linear energy weighting in CT [9, 10] is to weight and combine the energy-bin data after log normalization in order to reduce beam hardening artifacts. In this case, the optimal weights w_i are proportional to the contrast-to-noise-variance ratio (CNVR) of the reconstructed energy-bin images, as described in Eq. (1),

$$w_i \propto \frac{|\mu_{c,i} - \mu_{b,i}|}{\sigma_i^2} = \frac{C_i}{\sigma_i^2}, \quad (1)$$

where $\mu_{c,i}$ and $\mu_{b,i}$ are the average attenuation coefficients of the contrast element and background material, respectively, for the energy range of the ith bin.

The numerator in Eq. (1) reflects the contrast in the i th reconstructed energy-bin image and the denominator σ_i^2 reflects the noise variance. The contrast in each energy-bin image can measured from regions of interest (ROIs) in the reconstructed energy-bin images.

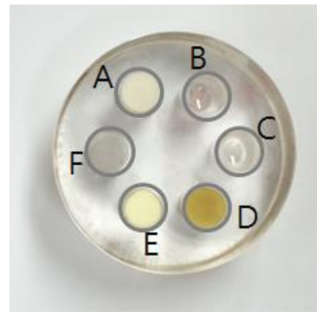

Figure 1. Image of phantom created personally containing inner bone (A), iodine (18.5 g/l) (B), iodine (37 g/l) (C), soft tissue (D), cortical bone (E), and air (F). The diameter of the phantom is 5cm, and the diameter of each material is 1cm. The height of the phantom is 3cm.

Figure 2. Image of phantom, Sendentexct IQ dental CBCT. It has materials, aluminum, PTFE, delrin, LDPE for measuring contrast resolution.

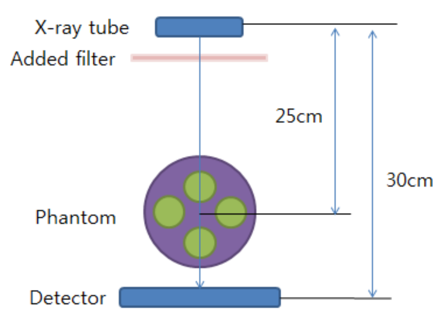

Figure 3. Diagram of the experimental set up.

As to the phantom, Sendentexct IQ dental CBCT, the images that processed with no other methods are scanned over 360° in 0.5° step. On the other hand, the images that processed with k-edge filter and energy weighting are scanned over 360° in 1.5° step. In terms of amounts of radiation dose, it has same aspect with methods of phantom created personally.

The reconstructed images were obtained by using simultaneous algebraic reconstruction technique (SART) [11-13] which is only one of the iterative reconstruction methods, 512 × 512 image matrix size, and 0.16mm slice thickness.

The mean and standard deviation of the reconstructed image value were measured inside five circular ROIs placed at regions representing cortical bone, inner bone, soft tissue, iodine(18.5g/l), iodine(37g/l) (Fig.2) on images reconstructed with SART.

To demonstrate the effect of K-edge filter and energy weighting method, contrast-to-noise ratio (CNR) was measured in each materials and compared between images without other methods processing. CNR was calculated using a MATLAB program and the following equation:

$$\mathrm{CNR} = \frac{\mu_{obj}-\mu_{bg}}{(\sigma_{obj}+\sigma_{bg})/2}, \quad (2)$$

where μ_{obj} and μ_{bg} are the average attenuation coefficients of the contrast element and background material, and σ_{obj} , σ_{bg} are the standard deviation of the contrast element and background material.

III. Results

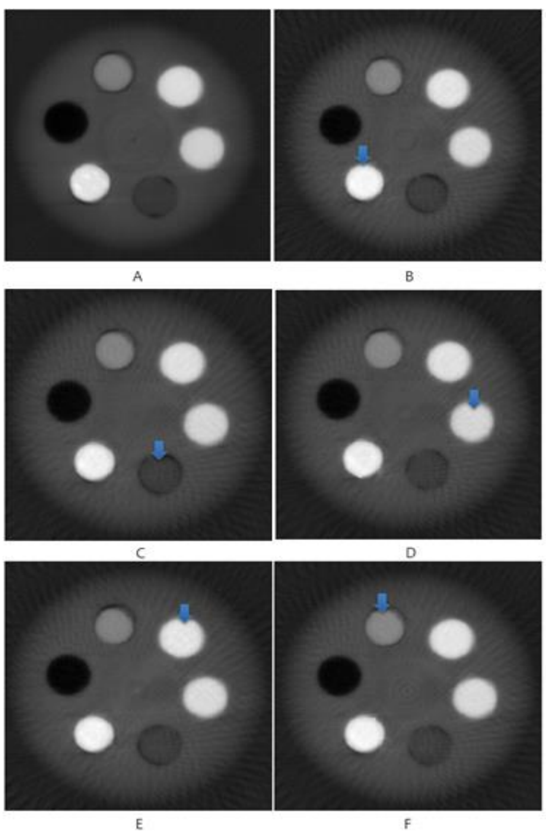

Figure 4. Reconstructed images of phantom created personally applied K-edge filtering and energy weighting. A is the standard image with none additional method. B is the image that weighting for optimize imaging cortical bone, C is for soft tissue, D is for iodine(18.5g/l), E is for iodine(37g/l), and F is weighted for inner bone.

As shown in Table I, CNR measured in reconstructed images of phantom created personally with K-edge filtering and energy weighting method seems to be improved than CNR of standard images. With energy weighting method for optimizing each material, cortical bone, soft tissue, iodine(18.5g/l), iodine(37g/l), and inner bone, improvement of CNR about each material was about 31% to 81%. 81% increase in CNR about energy weighting for optimizing cortical bon. About soft tissue, CNR is improved by 31%.

Table II compares the CNR values for the images of 'Sendentexct IQ dental CBCT' reconstructed with additional methods and the CNR of standard images. The listed values show that energy weighting methods for optimizing each material make the improvement of CNR. Comparing the CNR of images obtained with K-edge filtering and energy weighting and the CNR of images scanned with none additional methods but in two thirds of full radiation dose, methods for aluminum made the 15% improvement of CNR and methods for LDPE enabled to get 5% improvement of CNR. But, comparing with standard images, CNR of images with additional methods did not have much enhancement.

TABLE I: CNR of each material of image of phantom created personally reconstructed with iodine-filter and energy weighting method.

Materials	**CNR of materials with none weighting**		**CNR of materials with weighting for each material**				
	Full-dose	***2/3 dose***	***Inner bone***	***Cortical bone***	***Soft tissue***	***Iodine (18.5g/l)***	***Iodine (37g/l)***
Inner bone	***11.07***	***10.42***	***18.14***	***18.02***	***16.13***	***15.53***	***16.22***
Cortical bone	***31.01***	***28.03***	***53.22***	***56.36***	***49.51***	***50.93***	***49.73***
Soft tissue	***3.51***	***2.99***	***5.42***	***5.99***	***4.63***	***4.37***	***4.78***
Iodine(18.5g/l)	***27.89***	***25.43***	***45.2***	***45.67***	***43.14***	***43.41***	***42.15***
Iodine(37g/l)	***30.37***	***28.76***	***48.04***	***49.34***	***44.29***	***44.23***	***46.37***

TABLE II: CNR of each material of image of 'Sendentexct IQ dental CBCT' reconstructed with iodine-filter and energy weighting method.

Materials	**CNR of materials with none weighting**		**CNR of materials with weighting for each material**			
	Full-dose	***2/3 dose***	***PTFE***	***Delrin***	***Aluminum***	***LDPE***
PTFE	***24.46***	***21.93***	***25.16***	***19.46***	***20.43***	***19.77***
Delrin	***7.01***	***6.44***	***4.35***	***7.43***	***5.58***	***4.3***
Aluminum	***35.05***	***31.3***	***20.32***	***28.98***	***36.18***	***27.63***
LDPE	***9.62***	***8.63***	***7.03***	***8.5***	***9.04***	***9.1***

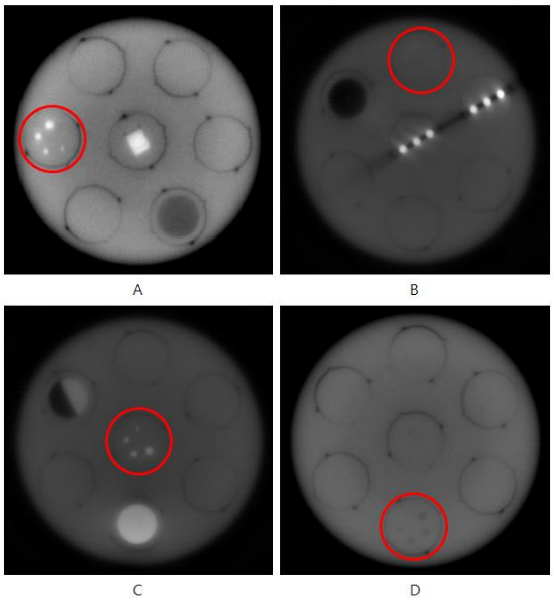

Figure 5. Images of 'Sendentexct IQ dental CBCT' reconstructed with K-edge filtering and energy weighting. A is the image that weighting for optimize imaging PTFE, B is for delrin, C is for aluminum, and E is for low density polyethylene (LDPE).

IV. Discussion

In general, the lower energy photons contain the most contrast information. However, low-energy photons are generally most corrupted by scatter and spectrum tailing, an effect caused by the limited energy resolution of the detector [10]. Also, image noise is inversely related to the square root of the total number of photons used to reconstruct the image. So that, low-energy data contain more noise in imaging. For this reason, an appropriate combination of low-energy and high-energy data can improve the quality of CT images by optimizing reduction the image noise and relatively increase in the contrast information.

Using iodine K-edge filter, we obtained two different CT images. The non-filtered images are considered to relatively low-energy; on the contrary, the filtered images are scanned for high-energy [9]. And then, these data were reconstructed with energy integrating, and optimal linear weighting method. We applied these methods to CT images with two thirds of radiation dose in radiography. Keeping radiation dose as low as reasonably achievable (ALARA) is the guiding principle for CT examination. Many techniques and strategies are available for radiation dose reduction [6, 14]. Among these many methods for reducing radiation dose, our strategies belong to class of noise control strategies in data processing and scanning technique.

In conclusion, overall, the result of this study demonstrates the improvement of the image CNR with K-edge filtering and energy weighting methods then origin image. We got CNR enhancement in the image with lower dose radiation, and this approach provides the other methods for advancing quality of image in reducing radiation dose. But, the improvements of the CNR of each material are rather different. According to the equation in energy weighting methods, weighting factor depends on the difference of attenuation coefficients of the contrast element and background. If the difference is smaller, the effect of weighting factor on CNR improvement is slight. So that's why there is the distinction in enhancement of CNR with each material.

For the future study, one possibility is the application of a photon counting x-ray detector, which allows counting each x-ray photon separately and measuring its energy. With this photon counting detector, the more exact K-edge filtering and energy weighting would be possible.

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