Successive iterative restoration applied to streak artifact reduction in X-ray CT image of dento-alveolar region

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Successive iterative restoration applied to streak artifact reduction in X-ray CT image of dento-alveolar region

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Abstract

Purpose X-ray computed tomography (CT) images in the dento-alveolar region are sometimes rendered unusable for diagnostic purposes due to the appearance of streak artifacts. The purpose of the study is to reduce streak artifacts appeared on dental and maxillofacial X-ray CT images by the application of modified iterative restoration method.

Methods CT images having streak artifacts was processed using the projection data of adjacent CT images which often depict very similar anatomical structures within the resulting collection of thin-slice images. We took advantage of this aspect and employed a modified iterative correction, the maximum likelihood-expectation maximization (ML-EM) reconstruction algorithm, to reduce the streak artifact caused by metallic materials in the oral cavity. It approximates between the processed image and the original projection data. First the projection data of an intact image was obtained and then the next image which had streak artifacts was processed. The projection data of the processed image were obtained and the ML-EM method was applied to the next image. Then the successive iterative restoration was carried out.

Results Twelve adjacent images were processed. Each iterative restoration was carried out fifty times. Streak artifacts were observed on processed images at the initial stage, but some of them either weakly appeared or disappeared as the iteration progressed.

Conclusions The modified ML-EM method was effective to reduce streak artifacts in X-ray CT images in dento-alveolar region.

Key words: X-ray CT image, Computer assisted image processing, Iterative restoration, Streak artifact reduction, Dento-alveolar imaging, Maxillofacial imaging

Introduction

X-ray computed tomography (CT) images in the dento-alveolar region are sometimes rendered unusable for diagnostic purposes due to the appearance of streak artifacts. The artifacts are often caused by the presence of metallic prosthetic appliances which have high atomic numbers and high density, but are also caused by, e.g., dental fillings in the oral cavity [1–5].

The metallic prosthetic appliances partly cause the lack of the projection data during the CT examination. Therefore, the resulting CT sinogram is often corrupted by the missing data. And as a result, the filtered back projection (FBP) algorithm, the traditional CT reconstruction method used for cross-sectional image reconstruction, cannot deal with such metal-induced inconsistencies, and the sinogram is rendered useless. However, several algorithms have been proposed for the reduction of metal-induced streak artifacts [6–11]. In some reports, the corrupted portions of the sinogram are replaced by uncorrupted data using appropriate interpolation methods.

In contrast, statistical reconstruction methods have been applied for image reconstruction in emission CT. For example, this type of application has been reported for the reduction of streak artifacts [12,13]. Moreover, the huge amount of computational efforts which this method requires has been resolved by the advancement in computer hardware. The statistical reconstruction method is sometimes called the algebraic iteration method. That is, these are reconstruction methods that use an iterative restoration algorithm. For dento-alveolar region imaging, Morita [14] first applied algebraic iteration to CT reconstruction and Webber and colleagues [15] developed the tomo-synthesis using iterative restoration.

However, our approach is quite different from those described in previous reports [16]. Due to advancements in hardware and software in CT systems and clinical needs, the CT examination with thin slice thickness is carried out in the dento-alveolar region as well as head and trunk regions. We found that an artifact-free/intact slice depicted very similar anatomical structures to the adjacent slice that contained the heavy streak artifacts, so they were the target of the proposed processing [16]. Therefore, we applied the maximum likelihood-expectation maximization (ML-EM) reconstruction algorithm to MDCT (Multi Detector Computed Tomography) images. After all, the processing was practically an iterative correction.

In the previous report, a slice having heavy streak artifact was processed using the projection data of an intact slice [16]. But there are several slices (seven slices in each 0.5 mm thickness) between them, and some streak artifacts were observed on the seven images. As the result, some deviations between the original image and the processed image were indicated. The objective of our research was to apply the successive iterative restoration to an image with streak artifacts using the immediate neighboring artifact-free slice for the artifact reduction for minimizing anatomical structure deviations.

Materials and Methods

Image acquisition

The MDCT examination of the maxillary sinus and maxilla was carried out using a Somatom® Plus 4 Volume Zoom (Siemens, Erlangen, Germany). Principal exposure parameters were as follows: 120 kV, 130 effective mAs, and a slice thickness of 0.5 mm. The pixel matrix of each slice was 512 × 512. Severe metal-induced streak artifacts occurred at several tooth crowns in the maxilla, and in addition, the overlapped regions were invisible.

The MDCT images with streak artifacts were selected as shown in Fig. 1, and they were objects of the proposed processing. Continuous twelve images in order from Head to Foot are shown. The adjacent image to Image No. 1 (the far left image on the top row in Fig. 1) is streak artifact-free/intact slice.

Projection data acquisition

Projection data acquisition was carried out as described in the previous report [14, 16]. The projection data were acquired at 360 directions with 1° intervals. The calculation of the detectability of each pixel at the detector is as follows. When the X-ray projection traverses each pixel, the shape of each pixel is usually a trapezoid depending on the angle between the projection and each pixel square. In special cases, projection shapes of square pixels become either a square at 0°, 90°, 180°, and 270° or a triangle at 45°, 135°, 225°, and 315° when the coordinate axes are set along edges of the image. If the shape of the projection is not square, the detectability is divided by the center of the detector element and neighboring elements. Each pixel on the image has a CT number, which is proportional to the X-ray transparency. The detectability of all pixels was accumulated and normalized along the projection whose width was set at 30 pixels.

Projection data acquisition of an image next to Image No. 1 in Fig. 1 was carried out at first. Our trial was to reduce streak artifacts from Image 1 in Fig. 1 using the projection data of the intact image in neighbor. And successively Image No. 2 in Fig. 1was processed using the projection data of the processed Image No.1 and went to the next (succeeding ones).

Iterative restoration

The adjacent images depicted very similar anatomical structures, so we reconstructed images containing streak artifacts by the projection data of the adjacent image. Firstly Image No. 1 and the projection data acquisition of the intact image next to Image No. 1 are compared. Differences between them are adjusted, and the image with streak artifacts was changed accordingly. The ML-EM reconstruction algorithm was applied. The ML-EM is an iterative restoration method that results in an approximation between the processes image and the original projection data.

The formulation of the ML-EM method is described as follows:

$$\lambda_j^{(k+1)} = \frac{\lambda_j^{(k)}}{\sum_{i=1}^{n} C_{ij}} \sum_{i=1}^{n} \frac{y_i C_{ij}}{\sum_{j'=1}^{m} C_{ij'} \lambda_{j'}^{(k)}}$$

The λ (Ramda) value is the output at each pixel. Other parameters are as follows;

k : the counter of iteration (loop variable)

j : the number of pixel (1 ~ m), m = 262144 if the image matrix is 512 x 512.

i : the number of detector's element (1 ~ n)

C_{ij}: detectability as the relation of pixel (i) and detector's element (j)

y_i: the projection data by the pixel (i)

The formula is also described in other articles [12-14].

The ML-EM reconstruction algorithm was employed to images. The flow of the method is as follows:

1. Select Image No. 1.
2. Get the projection data of the intact image next to Image No. 1.
3. Compare the projection data of the intact image with the practical projection data of Image No. 1
4. Compute the correction coefficient and reconstruct Image No. 1.
5. Stop the iteration when it meets the end condition and get processed image (Image No.1).
6. Replace Image No. 1 with Image No.2 and an intact image with the processed Image No.1. Return to Step 1.
7. Repeat from Step 1 to Step 6

First the projection data of the intact image (next to Image No. 1) was obtained and then the next image (Image No.1) which had streak artifacts was processed. The projection data of the processed image (Image No.1) were obtained and the ML-EM method was applied to the next image (Image No.2), and the iterative restoration was successively carried out.

In the previous report, changes in processed images were indicated according to the cycle number of iterations [16]. The blurring image was presented in the initial stage, but the blurring was gradually reduced with further iterations. Then images resulted from 1st, 2nd, 5th, 10th, 20th, 30th, 40th and 50th iterations were presented. And more than 50 cycles of the iteration showed that the remaining small artifacts were never removed [16]. Therefore, the cycle of iterations was set at 50 as the maximum in this study.

Image subtraction

Twelve subtracted images between initial images, which contained streak artifacts as shown in Fig. 1, and the processed images after the successive iterative correction, were made by the free software, ImageDiff (http://download.cnet.com/ImageDiff/3000-2192_4-10401778.html, accessed in Aug. 2010).

Results

The image and the projection data obtained from an artifact-free image, which is next to Image No. 1 in Fig. 1, are shown in Fig. 2(a, b), and also the projection data of Image No. 5 in Fig. 1, as an example, are shown in Fig. 2c. The projection data in Fig. 2(b, c) are usually called the sinogram. Comparing the projection data of the two images, the sinogram corruption by the metal presence is observed in Fig. 2c.

Fig. 3 shows twelve reconstructed images by the proposed processing. These images are corresponding to twelve images in Fig. 1. The ML-EM algorithm was carried out 50 cycles to images using the projection data of the immediate neighboring processed image. Namely, Image No. 2 was processed using the processed Image No. 1, and Image No. 3 was processed using the processed Image No. 2, and the processing was carried out to Image No. 12 in the same way. After the processing, streak artifacts were reduced obviously, but some of them never disappeared.

Twelve subtracted images are shown in Fig. 4. They are subtracted images between the original images (Image No. 1 to No. 12 in Fig. 1) and processed images (Image No. 1 to No. 12 in Fig. 3) respectively.

The PC used had an Intel^{R} Core^{TM} 2 Duo CPU running at 3.16GHz and 2.83GHz and Windows Vista. The time required for the iteration calculation of 50 cycles was approximately 6 min.

Discussion

The ML-EM algorithm is one of many iterative restoration methods used to obtain the optimal solution [12-14]. The findings in the previous study indicated that the streak artifacts were mostly reduced by the repeated cycles of correction [16]. Currently, streak artifacts are unavoidable in clinical X-ray CT scanners due to the presence of, e.g., metallic objects. Our iterative approximation method allows the reconstruction of the CT image using uncompleted projection data. However, subtracted images showed differences to some extent between original images and processed images [16].

The cycle of iterations as the maximum, was set at 50 in the study, due to the results of previous study [16]. Iterations were tried to 100 cycles practically, but no significant changes in artifact appearances were shown. As shown in Fig. 1, heavy streak artifacts from at least four dental metallic prosthetic appliances can be observed on original images, Images No. 9 to No. 12 in particular. But some of them were clearly reduced by 50 cycles of iterations, as shown in Fig. 3. Weakened streak artifacts at the left molar regions were observed on processed Image No. 4 and the following images. The remaining weakened artifacts were never removed even if more than 50 cycles. Since streak artifacts of Image No. 9 and the following images very too heavy to reduce using the proposed method, effects were restrictive.

The subtracted images in Fig. 4 show the differences between the original images (Fig. 1) and the processed images (Fig. 3), respectively. Some deviations between images were observed, but they were reduced in comparison with our previous study [16].

The time required for the calculation was dependent on the PC performance, then we could reduce the time in this study, but it is also dependent on the amount of streak artifacts. Small streak artifacts reduce the time needed for the calculation. In addition, the Ordered Subset-Expectation Maximization (OS-EM) reconstruction algorithm is the method used to reduce the calculation time in comparison with the ML-EM algorithm. It's clinically used for PET and SPECT examinations in nuclear medicine. The OS-EM algorithm is thought to be applicable for streak artifact removal from CT images.

The projection data were acquired at 360 directions with 1º intervals. In the next step, while the projection data will be reduced, the streak artifact reduction will be archived in processed images. Then the proceeding time will be expected to decrease. The partial lack of the projection data in CT examinations is usual in clinical practice. Namely sometimes only a limited number of views are available for the reconstruction [17]. Therefore the ML-EM algorithm can provide a solution.

The study was carried out using MDCT images as same as our previous study [16], but similar streak artifacts are also observed on dental Cone Beam Computed Tomography (CBCT) images [1]. The ML-EM and OS-EM algorithms are thought to be applicable for streak artifact removal from CBCT images. Our trial focused on MDCT images since streak artifacts are remarkable in comparison with CBCT images. Since The CBCT examination is carried out with thin slice thickness in the dento-alveolar region, adjacent slices depict very similar anatomical structures. Therefore there seems to be the benefit of the application of the ML-EM reconstruction algorithm which was proposed here and the previous study [16].

In conclusion, streak artifact reduction in dento-alveolar CT images was achieved by 50 cycles of the iterative restoration using the ML-EM reconstruction method. Since images contained intense amounts of metal-induced streak artifacts, weakened artifacts are still observed on the processed images. Since successive iterative restoration using the immediate neighboring slice was applied to an image with streak artifacts, the metal-induced streak artifact reduction was achieved at the same time as anatomical structure deviations were minimized.

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Figure legends

Fig. 1 Continuous twelve images are aligned from Head to Foot, from No.1, the far left side on the top row, to No. 12, the far right side on bottom row. These are original images on which streak artifacts appeared and objects for the proposed processing.

Fig. 2(a, b, c) **a:** The image obtained from the artifact-free/intact image, which is next to Image No. 1 in Fig. 1 **b:** The projection data obtained from **a**, **c:** The projection data of Image No. 5 in Fig. 1.

Fig. 3 Processed images of Image No.1 to No. 12, corresponding to twelve images in Fig 1.

Fig. 4 Twelve subtracted images between twelve initial images in Fig. 1 and their processed images in Fig. 3.

Figures

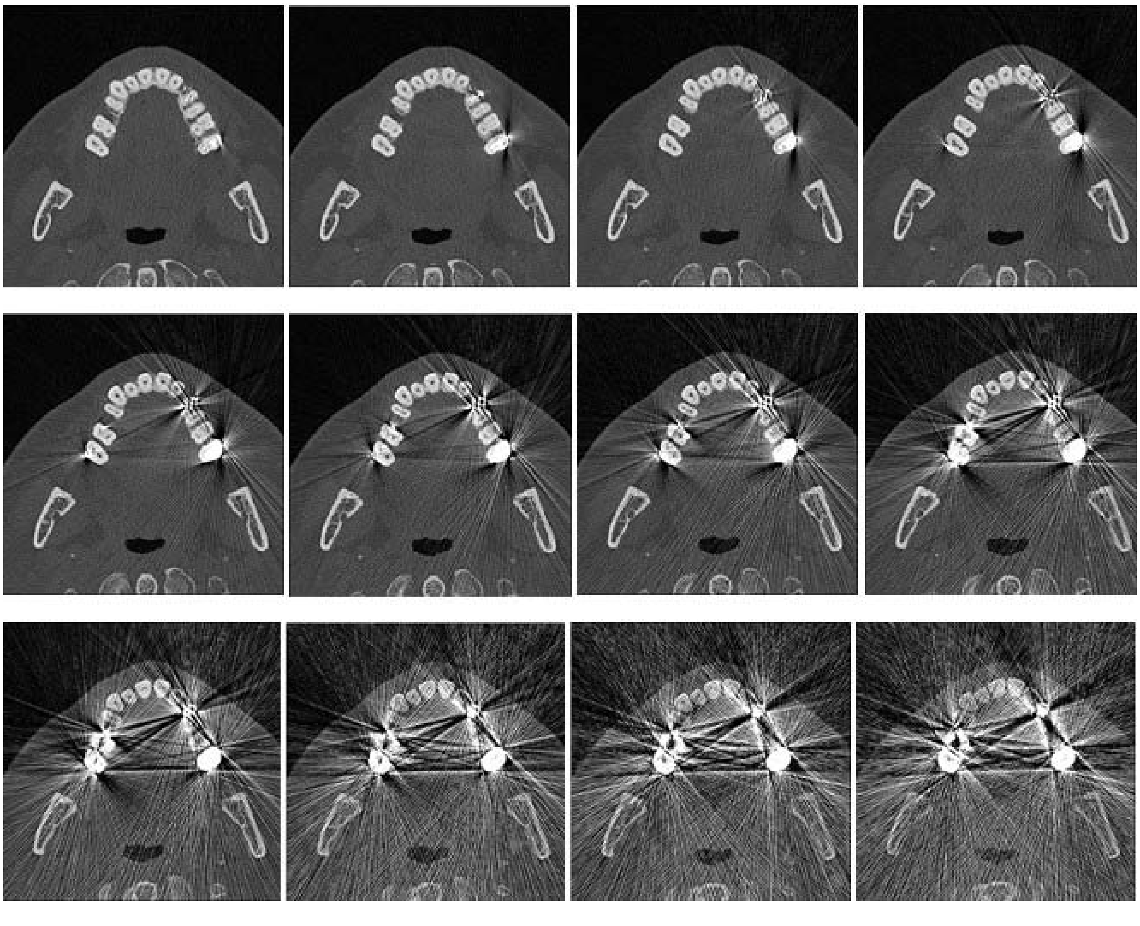

Fig. 1

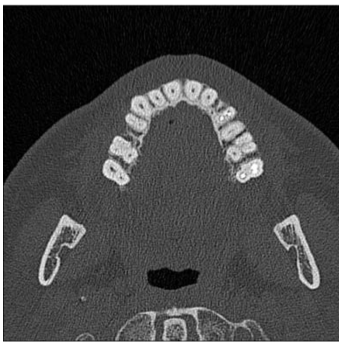

Fig. 2a

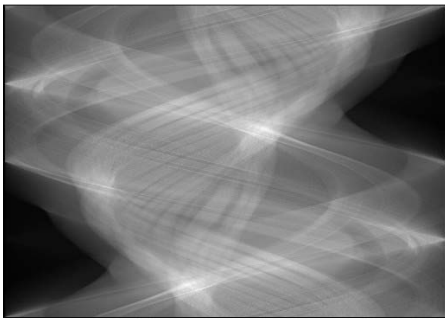

Fig. 2b

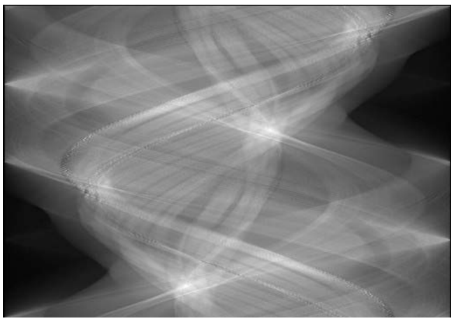

Fig. 2c

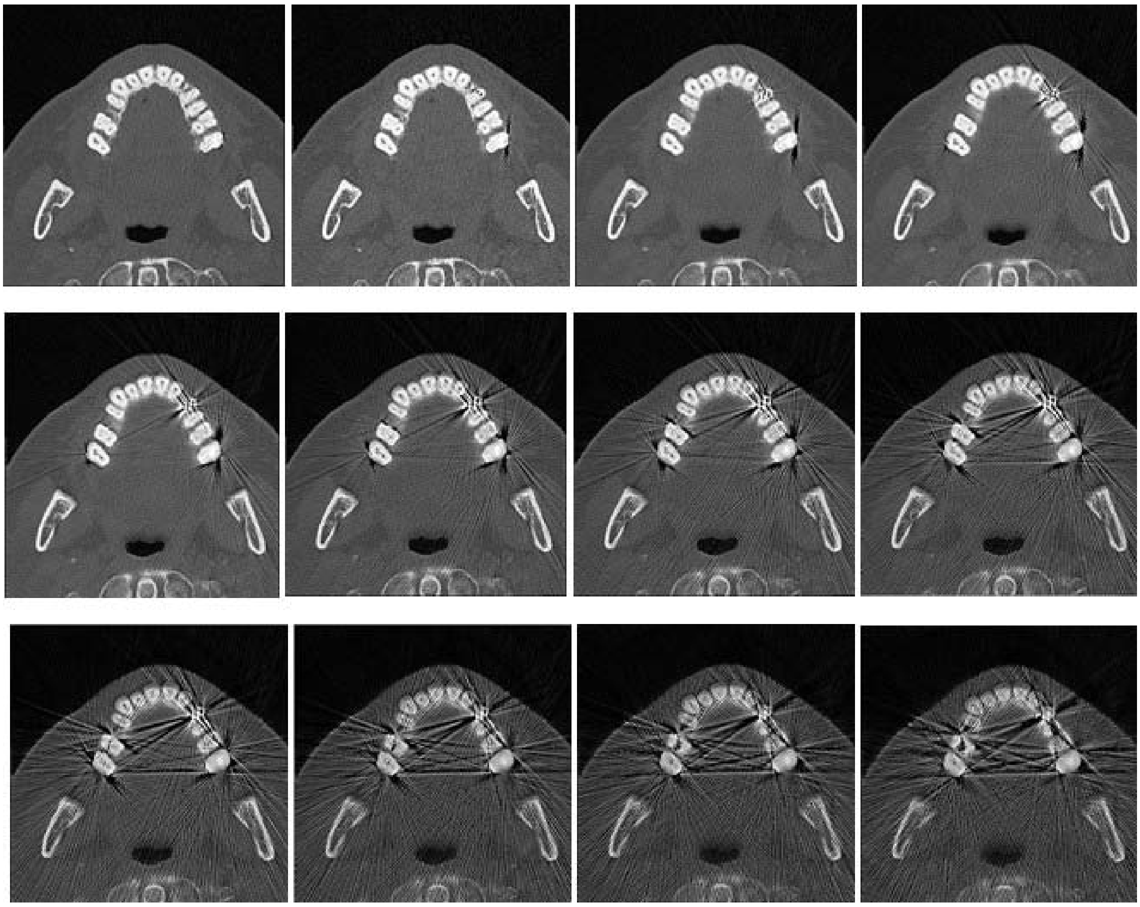

Fig. 3

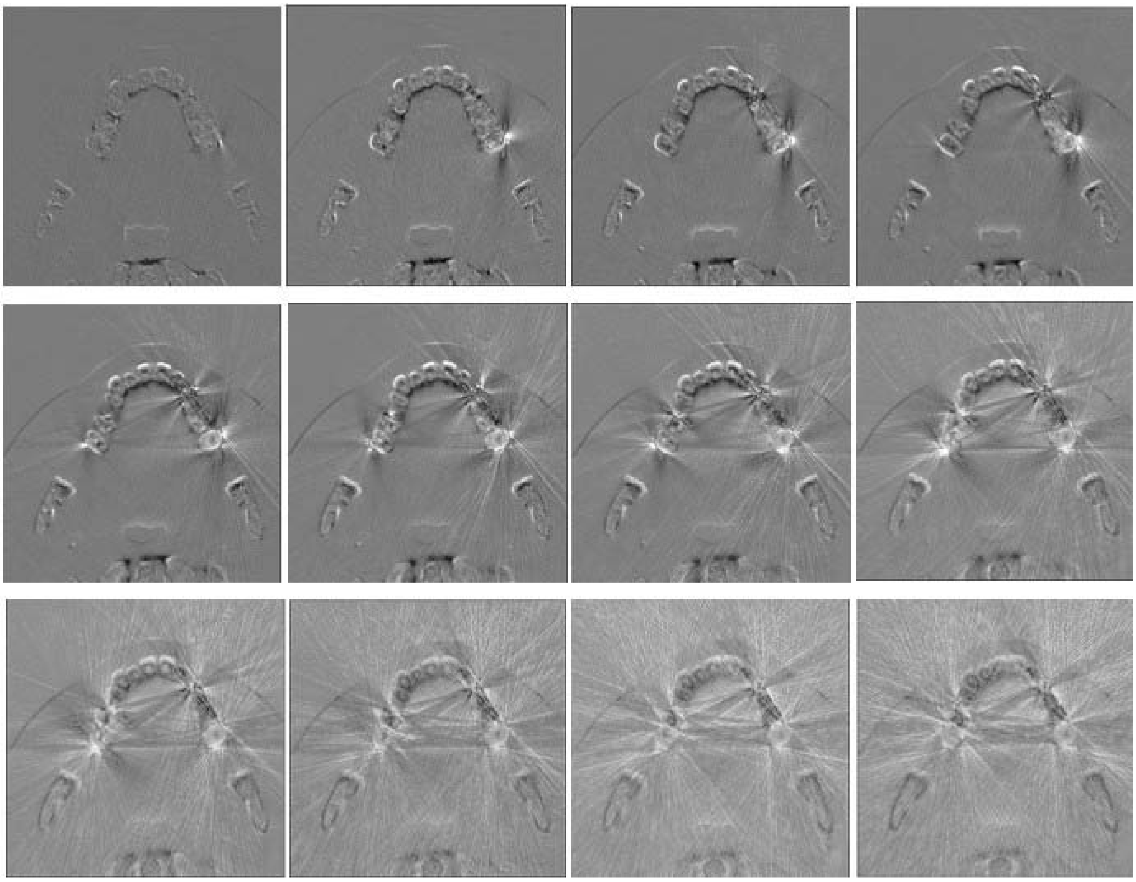

Fig. 4