Title:

Iterative correction applied to streak artifact reduction in an X-ray computed tomography image of the dento-alveolar region

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Abstract

Objectives: Streak artifacts that appear on dental and maxillofacial X-ray computed tomography (CT) images are mainly caused by the presence of metallic prosthetic appliances. Due to the design of common CT hardware, a method of thin slice thickness is routinely applied to CT examinations of the dento-alveolar region. Thus, within the resulting collection of thin slice images, adjacent CT images will often depict very similar anatomical structures. We took advantage of this aspect and employed iterative correction to reduce the streak artifact caused by metallic materials.

Methods: The maximum likelihood-expectation maximization (ML-EM) reconstruction algorithm, a type of statistical reconstruction method, was applied to multidetector CT (MDCT) images. The ML-EM is an iterative restoration method that approximates between the processed image and the original projection data. In our study, we processed slices with heavy streak artifacts by using the projection data of an adjacent CT image without any major artifacts. Since the adjacent slices depicted very similar anatomical structures, they became the target of the proposed processing. Thus, the processing is essentially an iterative correction.

Results: The iterative correction was carried out 50 times. Processed images at the initial stage were blurred, but some streak artifacts clearly disappeared as the iteration progressed.

Conclusions: A ML-EM reconstruction algorithm can be used to modify iterative correction to reduce streak artifacts in dental and maxillofacial CT images. We used an image that contained heavy artifacts in our study, and after 50 iterative correction cycles, only a few weak artifacts remained on the processed image. The final image produced by our iterative correction method depicted clear anatomical structures and developed only marginal deviations from the original image.

Key words: Tomography, X-Ray Computed; Image Processing, Computer-Assisted; Radiography, Dental; Iterative Correction

Introduction

Dental and maxillofacial computed tomography (CT) images are sometimes rendered unusable for diagnostic purposes due to the appearance of streak artifacts that are often caused by the presence of metallic prosthetic appliances. These artifacts are observed not only on multidetector CT (MDCT) images but also, to some extent, cone-beam CT (CBCT) images. Moreover, streak artifacts not only appear because of the presence of metallic prosthetic appliances but are also caused by, e.g., dental fillings in the oral cavity and surgical aneurysm clips [1–4].

The metallic prosthetic appliances, which have high atomic numbers and high density, 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 [5–8]. In some reports, the corrupted portions of the sinogram is replaced by uncorrupted data using an appropriate interpolation.

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 [9,10]. Moreover, the huge amount of computational effort 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 [11] first applied algebraic iteration to CT reconstruction and Webber and colleagues [12] developed Tuned-Aperture CT (TACT), which is tomo-synthesis using iterative restoration.

However, our approach is quite different from those described in previous reports. Due to the advancements in hardware and software in CT systems and clinical needs, the CT examination with thin slice thickness is routinely carried out in the dento-alveolar region as well as other 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. Since they depicted very similar anatomical structures, they were the target of the proposed processing in our report. Therefore, we applied the maximum likelihood-expectation maximization (ML-EM) reconstruction algorithm to MDCT images. After all, the processing was practically an iterative correction. The aim of our research was to apply the iterative correction to an image with heavy streak artifacts using the artifact-free neighboring slice for the metal-induced streak artifact reduction.

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.

A MDCT image with heavy streak artifacts caused by metallic dental appliances (Fig. 1) and its adjacent artifact-free MDCT image (Fig. 2) were selected. Our trial was to reduce streak artifacts from the image in Fig. 1 using the projection data of the intact image in Fig. 2.

Projection data acquisition

Projection data acquisition of the image in Fig. 2 was carried out. This method is the same as those described in other articles, such as Morita [11]. 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.

Iterative correction

The image in Fig. 1 and the projection data acquisition of the image in Fig. 2 were compared. Differences between them were adjusted, and the image with heavy 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 processed image and the original projection data. The slice with heavy streak artifacts was processed using the adjacent intact slice, i.e., a CT image without major artifacts. The adjacent slices depicted very similar anatomical structures. The formulae of the ML-EM method is described in other articles [9–11].

Subtracted images between initial images, which either contained artifacts or were artifact-free, and the processed image after the iterative correction were made by the free software, ImageDiff (http://download.cnet.com/ImageDiff/3000-2192_4-10401778.html, accessed in Dec. 2009).

Results

The projection data obtained by the artifact-free MDCT image in Fig. 2 is shown in Fig. 3. At the initial stage, the image for the 1st iteration is simply the output-field definition (Fig. 4a). The processed MDCT image at the 2nd iteration is shown in Fig. 4b. The blurring image is presented, but the blurring is gradually reduced with further iterations. In the following figures, processed images at the 5th (Fig. 4c), 10th (Fig. 4d), 20th (Fig. 4e), 30th (Fig. 4f), 40th (Fig. 4g), and 50th (Fig.4h) iterations are presented.

Heavy streak artifacts from at least four dental metallic prosthetic appliances can be observed on the original image (Fig. 1), but some of them were clearly removed by the repeated cycles of correction, as shown in Fig. 4c–g. Finally, only two small streak artifacts at the left molar regions were observed after 50 cycles of the iterative correction (Fig. 4h). More than 20 cycles of the iteration were needed to reduce the streak artifacts. We tried more than 50 cycles of the iteration, but the remaining small artifacts were never removed and the noise that existed on the image uniformly increased.

Two subtracted images are shown in Fig. 5a and b. Figure 5a shows the image between the image with artifacts (Fig. 1) and the processed image at the 50th iteration (Fig. 4h). The other is the image between the artifact-free image (Fig. 2) and the processed image at the 50th iteration (Fig. 4h).

The PC used had a Pentium 4 CPU running at 2.53 GHz and Windows XP. The time required for the iteration calculation of 50 cycles was approximately 7 min.

Discussion

The ML-EM algorithm is a one of many iterative restoration methods used to obtain the optimal solution. The present findings indicated that the streak artifacts were mostly reduced by the repeated cycles of correction. Currently, the streak artifacts are unavoidable in clinical X-ray CT scanners since the analytical image reconstruction, filtered back-projection (FPB), is usually applied to uncompleted data collections due to the presence of, e.g., metallic objects. Our iterative approximation method, however, allows reconstruction of the CT image using uncompleted projection data.

Our approach was quite different from those of previous reports [5–10]. The CT examination with thin slice thickness is routinely carried out in the dento-alveolar region. We found that an artifact-free slice depicted very similar anatomical structures to the adjacent slice that contained heavy streak artifacts. Therefore the ML-EM reconstruction algorithm was applied to two MDCT images in Fig. 1 and Fig. 2 for the reduction of heavy streak artifacts using the artifact-free neighboring slice. The processing was practically an iterative correction. Several steps of the processing were shown in Fig. 4a–h since we discovered that the process of the metal-induced streak artifact reduction is carried out step-by-step. The two subtracted images in Fig. 5a and b show the differences between the two unprocessed images (Figs. 1 and 2) and the processed image at the 50th iteration, respectively. Some deviations from both images were observed.

The time required for the calculation was dependent on the PC performance, of course, 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 to the ML-EM algorithm. It is 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 study was carried out using MDCT images, but similar streak artifacts are also observed on dental CBCT images [2]. 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 the streak artifacts are remarkable in comparison to CBCT images.

In conclusion, streak artifact reduction was achieved by iterative correction using the ML-EM reconstruction method. The process of the artifact reduction was presented step-by-step. A few weak artifacts remained on the processed image after 50 cycles of iterative corrections, since the image processed contained intense amounts of metal-induced streak artifacts. Anatomical structures were depicted clearly and accompanied by only marginal deviations from the original image after the iterative correction method was carried out.

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Figure legends

Fig. 1. A MDCT image with heavy streak artifacts caused by metallic dental appliances.

Fig. 2. An artifact-free MDCT image. This is a neighboring slice to the slice with heavy streak artifacts shown in Fig. 1.

Fig. 3. The projection data obtained by the artifact-free MDCT image in Fig. 2.

Fig. 4. (a–h) Processed MDCT images at (a) the 1st iteration, (b) 2nd iteration, (c) 5th iteration, (d) 10th iteration, (e) 20th iteration, (f) 30th iteration, (g) 40th iteration, and (h) 50th iteration.

Fig. 5. (a, b) Subtracted images between (a) the original image with heavy streak artifacts in Fig. 1 and the processed image at the 50th iteration in Fig. 4h and (b) the artifact-free image in Fig. 2 and the processed image at the 50th iteration in Fig. 4h.

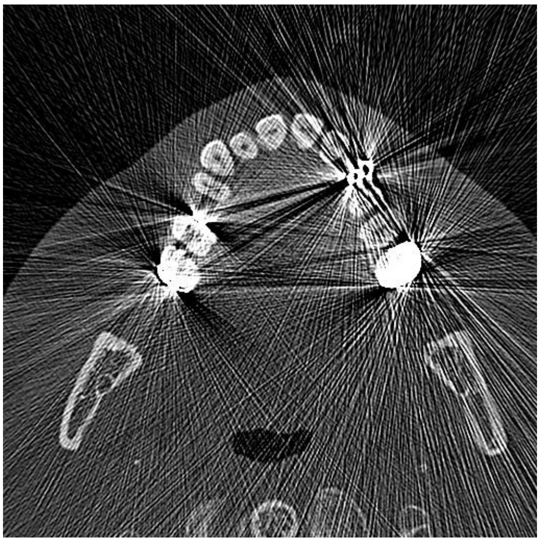
Fig. 1


Fig. 2

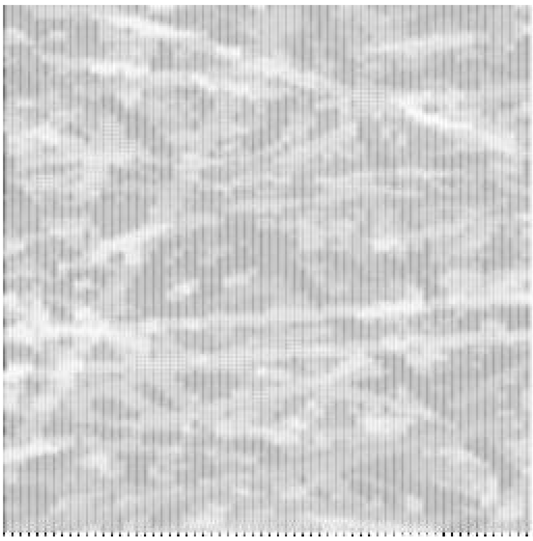
Fig. 3

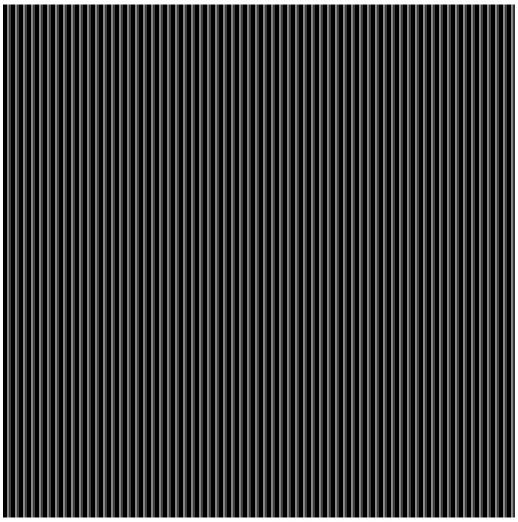

Fig. 4a

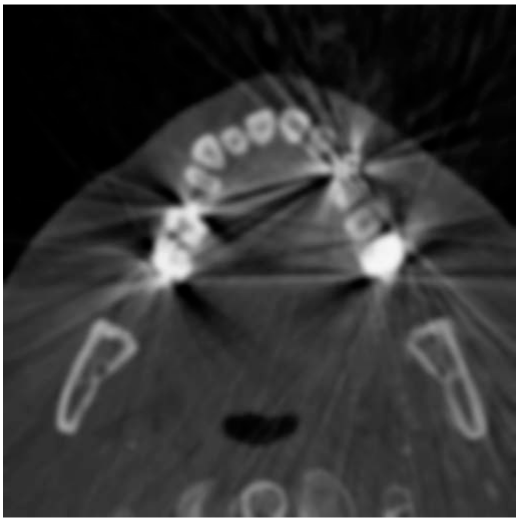

Fig. 4b

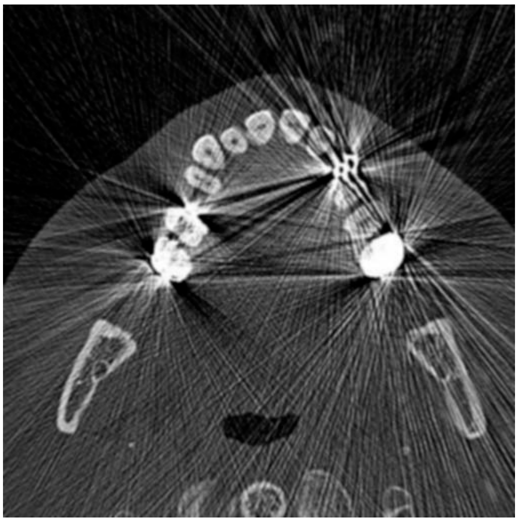

Fig. 4c

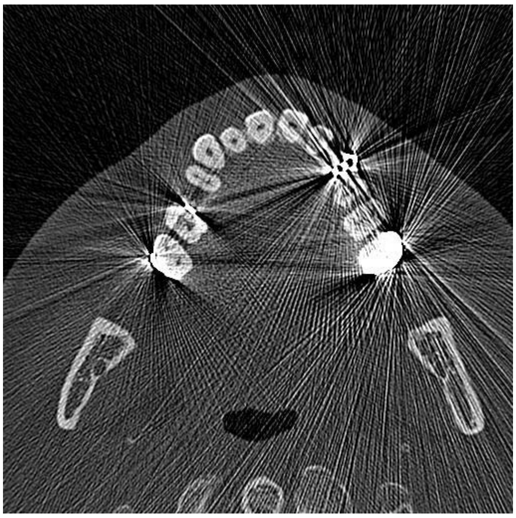

Fig. 4d

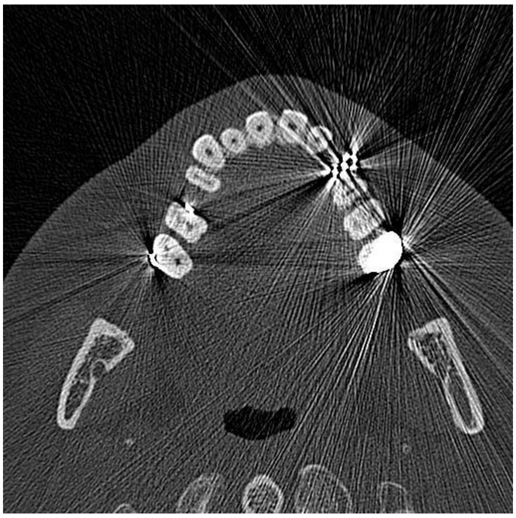

Fig. 4e

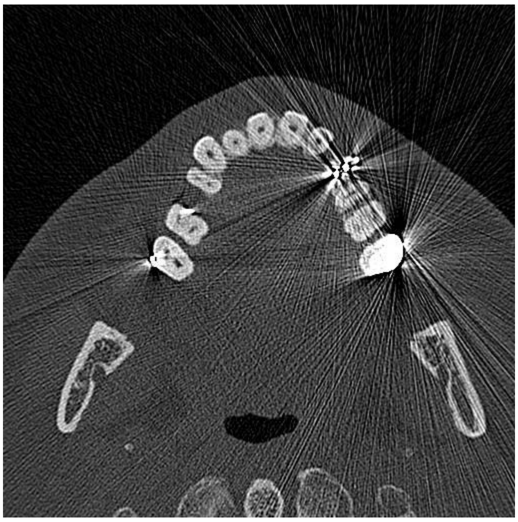

Fig. 4f

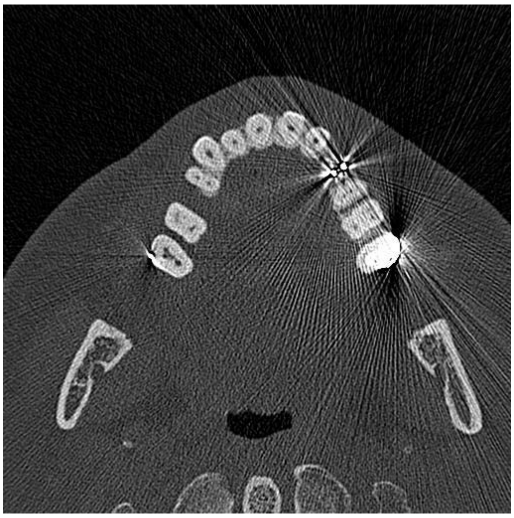

Fig. 4g

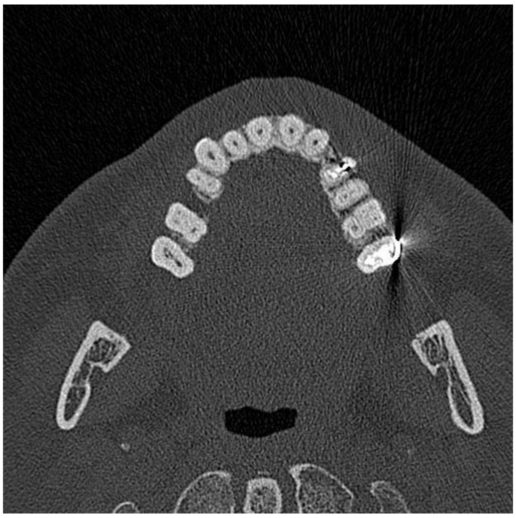

Fig. 4h

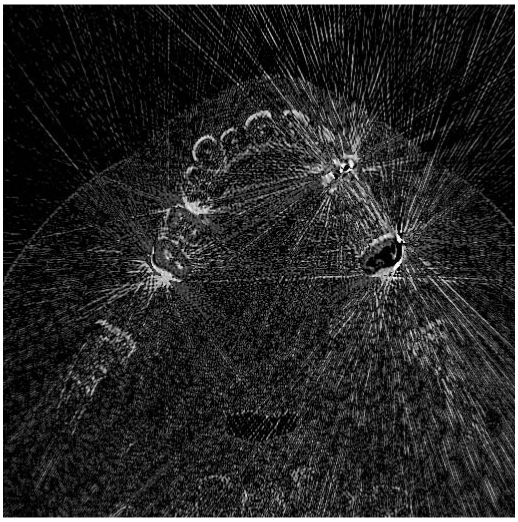

Fig. 5a

Fig. 5b