Metal-induced streak artifact reduction using iterative reconstruction algorithms in x-ray computed tomography image of the dentoalveolar region

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Objective. The objective of this study was to reduce metal-induced streak artifact on oral and maxillofacial x-ray computed tomography (CT) images by developing the fast statistical image reconstruction system using iterative reconstruction algorithms.

Study Design. Adjacent CT images often depict similar anatomical structures in thin slices. So, first, images were reconstructed using the same projection data of an artifact-free image. Second, images were processed by the successive iterative restoration method where projection data were generated from reconstructed image in sequence. Besides the maximum likelihood-expectation maximization algorithm, the ordered subset-expectation maximization algorithm (OS-EM) was examined. Also, small region of interest (ROI) setting and reverse processing were applied for improving performance.

Results. Both algorithms reduced artifacts instead of slightly decreasing gray levels. The OS-EM and small ROI reduced the processing duration without apparent detriments. Sequential and reverse processing did not show apparent effects.

Conclusions. Two alternatives in iterative reconstruction methods were effective for artifact reduction. The OS-EM algorithm and small ROI setting improved the performance. (Oral Surg Oral Med Oral Pathol Oral Radiol 2013;115:e63-e73)

Because x-ray computed tomography (CT) imaging has some advantages in features of tissue and spatial resolutions, the bony and soft tissue structures and related abnormalities are well-recognized for diagnosis. When x-ray CT examinations are carried out in dental and maxillofacial regions and there are metallic prosthetic appliances in the oral cavity, the appearance of metal-induced streak artifacts is not avoidable.[1-8] Such artifacts are observed not only on multidetector row CT (MDCT) images but also on cone-beam CT images.[7,8] The fixed metallic prosthetic appliances are often made of high atomic-number and high-density materials. The streak artifacts are also caused by dental fillings. Similar artifacts are also observed by the presence of other metallic biomaterials.[9-16]

Metallic biomaterials that are not only in the oral and maxillofacial region but also in other body regions cause the lack of projection data owing to high x-ray absorption coefficients.[4-6,10-12] The resulting sinogram patterns show the corruption by such missing data. The traditional CT reconstruction method, filtered back-projection (FBP) algorithm, cannot deal with such metal-induced inconsistencies. Some kinds of algorithms, however, have been proposed for metal-induced streak artifact reduction.[4-6,9-16] They usually take methods in which the partly corrupted sinogram data are repaired by either the replacement of intact data or the relevant interpolation.

The analytical reconstruction algorithm, such as the FBP, is the gold standard on almost all modern CT systems in clinics.[4,17,18] On the contrary, statistical reconstruction algorithms are an old idea but new technology for the quality improvement of CT images.[4,17-25] This has been applied for not only the image-quality improvement but also streak artifact reduction.[20,24,25]

In our previous studies, we focused on the fact that there were artifact-free slices next to slices having heavy streak artifacts but they depicted very similar anatomical structures. We attempted using the maximum likelihood-expectation maximization (ML-EM)

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Statement of Clinical Relevance

We provide the clinically applicable image-processing technique to reduce metal-induced streak artifacts that appear on x-ray CT images and improve the visibility of anatomical structures in the oral and maxillofacial regions. Some modifications for improving the performance are examined.

reconstruction algorithm and the successive iterative restoration to reduce metal-induced streak artifacts.[24,25] Kondo et al.[24] carried out the ML-EM algorithm to process a CT slice with heavy artifacts by using the projection data of the artifact-free slice on the neighboring slice. There were 7 slices (0.5 mm for a single slice) between the target slice and the artifact-free slice, namely they were 3.5 mm apart. The reduction of streak artifact was achieved, but some dimensional deviations were observed in the resultant images.[24] Then, Dong et al. applied the successive iterative restoration method.[25] First the projection data of the artifact-free slice was obtained. The adjacent slice, which showed weak artifacts, was processed. The projection data of the resultant image was used for the next neighboring slice. In this manner, the processing by the ML-EM and the computation of the projection data were repeated. The metal-induced streak artifact was well reduced on the resultant images and dimensional deviations were minimized. In general, statistical reconstruction algorithms necessitate the huge amount of computational efforts, as they are sometimes called the algebraic reconstruction technique. The ML-EM algorithm, which was used in previous studies, was a time-consuming procedure.[24,25] It took more than 6 minutes to reconstruct a 512 × 512 matrix image for 50-cycle iterations using our desktop PC.[25]

The ordered subset-expectation maximization (OS-EM) algorithm is the solution for fast computation.[21,23] The OS-EM divides the projection data to several subsets and carries out the processing procedures for each subset in sequence, and the procedures are projection, comparison, data renewal, and back projection, which belong to the given subset. In this study, we developed the fast statistical image reconstruction system using the iterative reconstruction algorithm, OS-EM, for the reduction of metal-induced streak artifacts on the dentoalveolar CT images. Moreover, the effects of the small region of interest (ROI) setting, the successive processing, and reverse processing methods were examined.

MATERIAL AND METHODS

Image acquisition

MDCT images of maxillary and partly mandibular jaws were acquired using a Somatom Plus 4 vol Zoom (Siemens, Erlangen, Germany). Principal exposure parameters were as follows: 120 kV, 130 effective mAs, and slice thickness was 0.5 mm. The pixel matrix of each slice was 512 × 512. The CT examination was carried out to examine the preoperative evaluation of bone morphology in maxilla for dental implant treatment. They were objects of the proposed processing procedures. The patient consented to the use of CT images for the study.

We acquired the original images in the order from head to foot. An artifact-free/intact slice was necessary for the iterative restoration method on the artifact reduction. Streak artifacts gradually appeared in many slices in maxilla and we could obtain an artifact-free CT slice that was an immediate neighbor to the first CT slice with weak artifacts in the head direction. The successive processing, to be hereinafter described, started at the combination of these 2 neighboring CT slices.

First, we applied the successive method to 12 images in maxilla as shown in Figure 1. They had weak or severe metal-induced streak artifacts. They occurred at either one or several tooth crowns and, as a result, overlapped regions were invisible. Also, we applied the same method to 8 images in mandible, as shown in Figure 2. Because this was a case of the CT examination for the preimplant operation in maxilla, we could not find an artifact-free CT slice in mandible. Weak artifacts were still observed at the bottom right slice.

Projection data acquisition

Projection data acquisition was carried out as described in the previous article.[24,25] Each pixel on the image has a CT number, which is proportional to the x-ray transparency. 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. There is a detector containing 512 pixels whose value is called detectability. During the detectability calculation, the value is accumulated by adding the respective pixels' CT number. If the shape of the projection is not square, the detectability will be divided by the center of the detector element and neighboring elements. The projection data were acquired in 360 directions with 1° intervals, so the pixel number was 512 × 360. As an example, an artifact-free/intact image, which is the next image to the first one at the far-left side on the top row in Figure 1, and the projection data (sinogram) computed from the artifact-free image are shown in Figure 3, *A* and *B*.

In this work, we chose 2 ways to process the images in maxillary CT images. In one way, we first obtained the projection data of the artifact-free image, namely the image that appeared in Figure 3, *A*. The continuous 12 images were all processed using the same intact image's projection data. In the other way, the projection data acquisition of the artifact-free image (Figure 3, *A*)