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Technical note

Evaluation of digital tomosynthesis reconstruction algorithms used to reduce metal artifacts for arthroplasty: A phantom study

Tsutomu Gomi *, Rina Sakai, Masami Goto, Hidetake Hara, Yusuke Watanabe, Tokuo Umeda

School of Allied Health Sciences, Kitasato University, Sagamihara, Kanagawa, Japan

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ABSTRACT

To investigate methods to reduce metal artifacts during digital tomosynthesis for arthroplasty, we evaluated five algorithms with and without metal artifact reduction (MAR)-processing tested under different radiation doses (0.54, 0.47, and 0.33 mSv): adaptive steepest descent projection onto convex sets (ASD-POCS), simultaneous algebraic reconstruction technique total variation (SART-TV), filtered back projection (FBP), maximum likelihood expectation maximization (MLEM), and SART. The algorithms were assessed by determining the artifact index (AI) and artifact spread function (ASF) on a prosthesis phantom. The AI data were statistically analyzed by two-way analysis of variance. Without MAR-processing, the greatest degree of effectiveness of the MLEM algorithm for reducing prosthetic phantom-related metal artifacts was achieved by quantification using the AI (MLEM vs. ASD-POCS, SART-TV, SART, and FBP; all $P < 0.05$). With MAR-processing, the greatest degree of effectiveness of the MLEM, ASD-POCS, SART-TV, and SART algorithms for reducing prosthetic phantom-related metal artifacts was achieved by quantification using the AI (MLEM, ASD-POCS, SART-TV, and SART vs. FBP; all $P < 0.05$). When assessed by ASF, metal artifact reduction was largest for the MLEM algorithm without MAR-processing and ASD-POCS, SART-TV, and SART algorithm with MAR-processing. In ASF, the effect of metal artifact reduction was always greater at reduced radiation doses, regardless of which reconstruction algorithm with and without MAR-processing was used. In this phantom study, the MLEM algorithm without MAR-processing and ASD-POCS, SART-TV, and SART algorithm with MAR-processing gave improved metal artifact reduction.

1. Introduction

Digital tomosynthesis (DT) combines the benefits of digital imaging [1–9] with the tomographic benefits of computed tomography to provide three-dimensional (3D) structural information, which can easily be implemented in conjunction with radiography at reduced radiation doses and cost. In contrast, DT reconstruction also involves inconsistent reconstructed images that are limited by a low signal-to-noise ratio due to the superposition of several low-exposure projection images.

In recent years, cementless hip arthroplasty has become increasingly popular in clinical practice, and reliable biological fixation is essential to the success of cementless hip arthroplasty [7]. Imaging of hip arthroplasty is an important tool to evaluate the postoperative placement of components and later to evaluate possible complications [9]. There are few reported prospective studies on the clinical utility of DT of hip prostheses clinically suspected of loosening.

Metal artifacts deteriorate image quality by reducing contrast and obscuring details, thereby hindering detection of structures of interest and possibly leading to misdiagnosis. In the presence of metallic joint prostheses or osteosynthetic materials, the metal implant and interactions among the implant, dose, and surrounding tissue should be evaluated. Hematoma or inflammation in the adjacent soft tissue must also be ruled out. However, metal artifacts greatly complicate evaluations of these features and frequently render the images uninterpretable by conventional image reconstruction. Especially, filtered back projection (FBP) [3] is used even with hard convolution kernels (Ramachandram [Ramp] or Shepp–Logan [SL] filter kernel). In DT, artifacts occur as very low signals along the sweep direction around the edges of highly attenuating materials, such as metal prostheses or osteosynthetic materials. These artifacts are predominantly caused by a mismatch between the assumptions of the reconstruction algorithm (ideal monochromatic beam) and reality (wide spectral range). The limited sweep angle also contributes but to a much lesser degree.

* Corresponding author at: School of Allied Health Sciences, Kitasato University, Kitasato 1-15-1, Minami-ku, Sagamihara, Kanagawa 252-0373, Japan.
E-mail address: gomi@kitasato-u.ac.jp (T. Gomi).

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The performance of the metal artifact reduction (MAR)-processing algorithm has been evaluated in computed tomography and DT research [8,10–12].

In addition to FBP, iterative reconstruction (IR) has been explored in DT for arthroplasty [4,5,7–8]. Compared with the FBP algorithm, IR has been shown to provide a good balance of improved image quality between low- and high-frequency features [5,7,8]. To date, only one study has quantitatively compared image quality and radiation doses for arthroplasty among several existing DT algorithms [5]. In that study, IR was found to effectively decrease quantum noise and radiation exposure; however, the evaluation was limited and merely compared existing algorithms (comparison of FBP vs. IR using the simultaneous iterative reconstruction technique [SIRT] [13] and maximum likelihood expectation maximization [MLEM] [14]). Therefore, it is necessary to evaluate the optimal radiation dose and image quality in prosthetic imaging using available novel reconstitution algorithms.

Recently, an iterative algorithm using total variation (TV)-based compressive sensing was developed for volume image reconstruction from a tomographic scan [15–19]. The image TV has been used as a penalty term in iterative image reconstruction algorithms [19]. The TV of an image is defined as the sum of the first-order derivative magnitudes for all pixels in the image. TV minimization is an image domain optimization method associated with compressed sensing theory [17,19]. As TV-minimization IR for image reconstruction, the adaptive steepest descent projection onto convex sets (ASD-POCS) algorithm yields an approximate solution to the constrained TV-minimization problem [17]. Another TV-minimization IR technique is the simultaneous algebraic reconstruction technique (SART) [18] with algebraic IR for constraining the TV-minimization problem, which is called SART-TV [19]. In TV-minimization IR, adding a penalty to the data-fidelity-objective function tends to smooth out noise in the image while preserving edges within the image [15–20]. Therefore, TV-minimization IR can improve image quality by reducing metal artifacts and the radiation dose.

In this study, we evaluated five reconstruction algorithms with and without MAR-processing [10], two TV-minimization IR algorithms (ASD-POCS and SART-TV), and three conventional reconstruction algorithms (FBP, statistical IR-MLEM, and algebraic

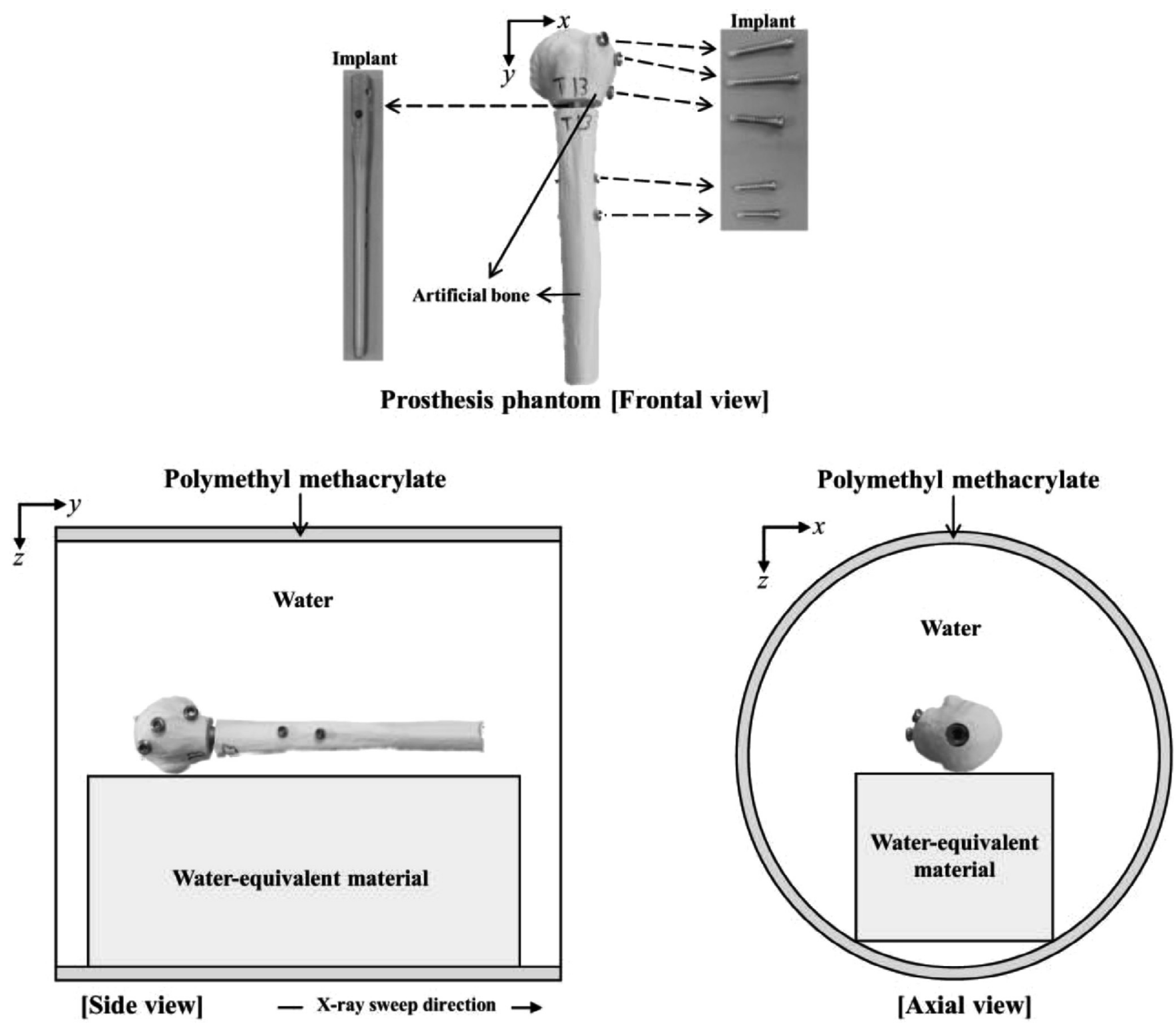

Fig. 1. Photograph of the prosthetic phantom (top) and geometric distribution (bottom) of the prosthetic phantom used in this study. The prosthetic phantom was arranged parallel to the detector plane.