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Research article

CT temporal subtraction method for detection of sclerotic bone metastasis in the thoracolumbar spine

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ABSTRACT

Purpose: To assess the effectiveness of a CT temporal subtraction (TS) method on radiologists' performance in sclerotic metastasis detection in the thoracolumbar spine.

Materials and methods: 20 pairs (current and previous CTs) of standard-dose CT and their TS images in patients with sclerotic bone metastasis and 20 pairs (current and previous CTs) of those in patients without bone metastasis were used for an observer performance study. A total of 135 lesions were identified as the reference standard of actionable lesions (sclerotic metastasis newly appeared or increased in size or in attenuation). 4 attending radiologists and 4 radiology residents participated in this observer study. Ratings and locations of "lesions" determined by the observers were utilized for assessing the statistical significance of differences between radiologists' performances without and with the CT-TS images in JAFROC analysis. The statistical significance of differences in the reviewing time was determined by a two-tailed paired *t*-test.

Results: The average figure-of-merit (FOM) values for all but one radiologist increased to a statistically significant degree, from 0.856 without the CT-TS images to 0.884 with the images (P = .037). The average sensitivity for detecting the actionable lesions was improved from 60.7 % to 72.5% at a false-positive rate of 0.15 per case by use of the CT-TS images. The average reading time with CT-TS images was significantly shorter than that without (150.6 s vs. 166.5 s, P = .004).

Conclusion: The use of CT-TS would improve the observer performance for the detection of the sclerotic bone metastasis in the thoracolumbar spine.

1. Introduction

Bone is one of the most common sites for metastasis in cancer alongwith liver and lung. Bone metastases tend to develop in the axial skeleton in a distribution that correlates with the location of red bone marrow such as vertebrae, pelvis, ribs, and the ends of long bones [1]. Spine is the most common site for bone metastases and spinal metastases were seen in 5 to 10% of all cancer patients during the course of their disease [2,3]. Over the past several decades, treatment strategies for cancer have developed, and many patients are living longer with metastatic disease and the incidence of skeletal metastasis is increasing [4,5]. In association with the increased prevalence of bone metastasis, the possibility of occurring significant comorbidities such as pain, pathological fracture, spinal or nerve root compression and hypercalcaemia has also increased [6]. Early diagnosis of spinal metastasis is important to avoid or reduce these comorbidities, and preserve or improve patients' outcome and quality of life [7–9]. In addition, it also changes treatment regimen from curative therapy to palliative treatment.

Bone scintigraphy is the common choice for whole body screening of bone metastasis, and positron emission tomography (PET) and whole body MRI are also useful to detect bone metastasis. Although CT is a routine imaging modality to survey many types of cancer, bone metastases are often missed at CT because of their subtle findings. CT demonstrate superior bony detail, allowing detection of bone metastasis. Other modalities are useful to detect bone metastasis, but they still must be identified at CT.

Some researchers reported that CT computer-aided detection (CAD) system potentially assist radiologists in detecting bone metastasis in the thoracolumbar spine [10–12], but the effectiveness of these CAD

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systems has not yet been verified by the observer performance study. The temporal subtraction (TS) technique is one of the CAD techniques in which a previous image is subtracted from a current image so that interval changes are enhanced. Aoki et al. have developed a new TS method in order to significantly reduce misregistration artifacts on the subtraction images in successive thoracic CTs, and had shown that TS can improve the diagnostic accuracy of lung nodules [13]. Subsequently, a couple of studies have reported the utility of CT-TS for the detection of the bone metastases recently [14–16]. However, the diagnostic performance of CT-TS for the detection of the bone metastasis has not been fully clarified. We have been developing a new CT-TS method using salient region feature (SRF). The purpose of this study is to assess the effectiveness of a CT-TS method for radiologist's performance in sclerotic metastasis detection in the thoracolumbar spine.

2. Materials and methods

Our institutional review board approved this study and informed consent was waived.

2.1. Computerized scheme

In available CT-CAD system lesion candidates are usually indicated by symbol/mark on a computer-output image. On the other hand, in the CT-TS system, observers refer to the subtraction image without symbol/mark and then judge whether a “lesion” existed or not. Therefore, diagnostic performance is heavily affected by the image quality of the subtraction image. In the CT-TS method we developed, the registration is achieved by image matching, image warping techniques. In addition to the conventional TS method, we employed a new local matching technique to determine best matched position based on SRF in order to significantly reduce misregistration artifacts [17]. Compared with the density based image registration method, the SRF is a more stable alignment which can be obtained without being influenced by the local density change. Fig. 1 shows the schematic diagram of a CT subtraction. First, thoracolumbar spine regions are segmented by using a preprocessing technique and graph cut algorithms from the previous and current images. Second, we perform global image matching using center of gravity and normalized cross correlation. The segmentation/image matching was performed in each vertebra separately. Third, we perform final image matching based on SRF. Finally, a CT-TS image is provided by subtraction of the matched-voxel, warped previous image from the current image, as shown in Fig. 2. The previous image is colored in red and the current image is colored in green. If a new lesion is appeared, it would be colored in green. Computational time for creating a temporal subtraction image set is about 70 min (Intel 3.4 GHz CPU with 8GB memory).

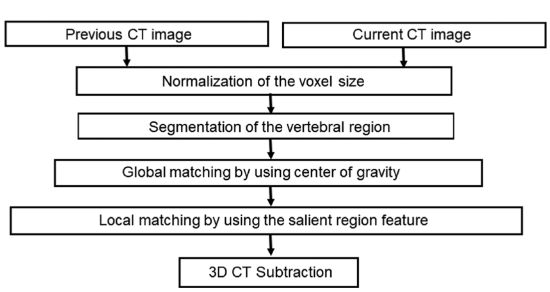

Fig. 1. Overall schematic diagram of our CT-temporal subtraction (TS) method. First, thoracolumbar spine regions are segmented by using a preprocessing technique and graph cut algorithms from the previous and current images. Second, we perform global image matching using center of gravity and normalized cross correlation. In addition to the conventional TS method, we perform final image matching based on a salient region feature (SRF) in order to significantly reduce misregistration artifacts.

2.2. Observer performance study

Forty pairs (current and previously obtained CT images) of 1-mm thin section CT images and corresponding CT-TS images in patients with malignancies; 20 pairs with positive findings and 20 pairs with negative findings, were used for an observer performance study. CT scans covering the vertebral body of Th1 to Th12 or L1 were obtained with a 32-, 64-, 80-, 320- detector row CT scanner (Toshiba Medical Systems) using the following technique: 0.5 or 1 mm collimation, 0.5 s rotation time, 120 kVp, and all images were reconstructed using an edge-enhancing kernel (FC52). Both postcontrast and nonconstrast CTs were included in the CT datasets for observer performance study. Automatic tube current modulation (z-axis modulation with Real E.C. technique, Toshiba Medical Solutions) was used with the noise level set at 10 SD.

At retrospective review of the chest CT files of patients who were seen at our institution between November 2013 and November 2016, we selected 20 consecutive cases with positive findings (9 men; mean age, 72.4 years, age range, 56–83 years; 11women; mean age, 67years, age range, 52–89 years; primary lesion location; breast, n = 9, prostate, n = 7, lung, n = 4) on the basis of the following selection criteria: previous chest CT image was available; current chest image had at least one lesion with sclerotic metastasis; increased in size or attenuation or demonstrated appearance of the sclerotic metastasis. One of them had the compression fracture of Th12. Two experienced musculoskeletal radiologists who did not participate in the observer study determined reference standards for the actionable lesion suspicious enough to warrant further follow-up. They detected the actionable lesion in consensus at a joint session before the observer study, with reference to continuing growth on further follow up CT, other imaging such as PET, MRI, bone scintigraphy, or by clinical data including the clinical history, symptom, and tumor marker.

A total of 135 actionable lesions (mean size, 14 mm ± 11.9 [standard deviation], size range, 3–57 mm) were identified. 29 lesions were smaller than 5 mm, 39 lesions were 5–10 mm, 35 lesions were 11–20 mm, and 32 lesions were larger than 20 mm in size. In 96 of the 135 lesions newly appeared where the previous CT showed no bone metastasis. In the remaining 39 lesions, increase in size or attenuation was identified on the current CT. Similarly, at retrospective review of the CT file, 20 consecutive cases with negative findings were selected for negative cases on the basis of the following selection criteria: previous 1 mm slice chest CT images were available, and there were no perceptible interval changes between current and previous CT examinations. The interval between current and previous CT examinations ranged from 25 to 1142 days (positive cases, range, 25–1142 days; negative cases range, 42–901 days).

Eight radiologists consist of four attending radiologists with at least nine years of experience (from 9 to 26 years) and four radiology residents with less than two years of experience (from 10 months to 20 months) participated in this observer study. An independent test consisting of two sessions of two series was performed. In the first session, half of the observers interpreted previous and current CT images alone while the other half of the observers interpreted the pair of CT and CT-TS images. In the second session, the same experiment was performed, with the data sets presented in an order that was different from that used in the first session. To reduce learning effects, the interval between the two sessions was maintained for at least 4 weeks or longer. Radiologists were blinded to patients' names, and patients' order was randomized.

A standalone personal computer-based reading tool with which to view stack images was used in this performance study (Fig. 3). Ratings and locations of lesions obtained with this tool were used to assess the significance of differences between radiologists' performances without and with CT-TS images. A radiologist who participated in this observer performance study was asked to identify the most likely location of an actionable nodule, if available, by clicking the left button of the mouse.