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New Image Processing Method for Plain Radiography Improves Detection of Bone Metastases

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Background: Diagnosis of bone metastases would be hastened if they could be detected on plain radiographs obtained at the first visit to an orthopedic surgeon. However, lesions are often undetectable on plain radiography. Bone metastasis is diagnosed at the first visit in only a few patients, and diagnosis is delayed in many cases. We investigated the diagnostic performance of plain radiography that used a new image processing method, Dynamic Visualization II (DV), to diagnose bone metastases.
Methods: We enrolled 29 patients with symptomatic pelvic bone metastases who visited our hospital between April 2018 and March 2021. The evaluation images were created by processing the original plain radiography data with the default settings for DV (Presets 1-4). Processing with Preset 1 resulted in an image converted to conventional film parameters, whereas Presets 2-4 utilized different DV processing methods. The readers were six orthopedic trainees, and the reading time was 30 seconds per image. The rate of correct answers for images processed with Preset 1 was compared to the rates for those processed with the other presets. Additionally, the rate of correct answers was analyzed in relation to clinical variables.
Results: The correct answer rate was significantly higher for Preset 3 (43.7%) and Preset 4 (42.5%) than for Preset 1 (28.7%). Correct answer rates for Presets 3 and 4 were significantly higher for elderly patients, male patients, patients with innominate bone lesions, patients with osteolytic bone metastases, and patients with a normal body weight.
Conclusions: Image processing by DV improved diagnosis of bone metastases by plain radiography. DV might hasten diagnosis of bone metastases and help prevent associated complications.
(J Nippon Med Sch 2025; 92: 37‒43)

Key words: bone metastasis, plain radiography, image processing, Dynamic Visualization II

Introduction

The elderly population of Japan is currently increasing, and elderly adults now account for 30% of the population[1]. The increase in this age group has led to an increase in the numbers of cancer patients and those with bone metastases. As bone metastasis progresses, it places a heavy burden on cancer patients, causing severe pain, pathological fractures, and spinal cord paralysis[2]. Treatments for bone metastases are improving, but early diagnosis and treatment are essential for patients to fully benefit[3].

Japan has a universal health insurance system that allows people to visit medical facilities at relatively low cost. Under this medical system, it is common to see an orthopedist without being referred by a general practitioner[4]. Most orthopedic clinics are equipped with plain radiography devices, and plain radiographs are obtained at the initial consultation. Nevertheless, among patients

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https://doi.org/10.1272/jnms.JNMS.2025_92-108
Journal Website (https://www.nms.ac.jp/sh/jnms/)

who presented with symptoms of bone metastasis, the condition was often not diagnosed or strongly suspected at the first visit and diagnosis was substantially delayed[2,5]. The reasons for this delay include the similarity in age and initial symptoms of patients with bone metastases and those with common diseases such as spondylosis deformans and sciatica, as well as the low detection power of plain radiography[2]. In a retrospective study of plain radiographs of symptomatic bone metastases at an initial visit, it was possible to detect bone changes caused by bone metastases in approximately 70% of the images[6]. This finding highlights the importance of orthopedists being aware that bone metastases can be coincident with common orthopedic diseases, thus necessitating careful examination of imaging findings.

Plain radiography has become increasingly digitalized. Image processing capabilities have improved because of developments in image analysis and image presentation technologies, resulting in improved image quality[7,8]. However, problems with conventional processing include contrast inconsistency because of the anatomy of the patient; inability to visualize entire areas of objects with large gaps in thickness; inability to enhance low-frequency structures, such as whole organs or large bone structures; and increased image granularity when enhancement processing is increased under some exposure conditions[9]. DV, the latest image processing technology developed by Fujifilm, aims to solve these problems by density and contrast stabilization processing using 3D structure estimation technology that recognizes the patient's body thickness and components from radiography information transmitted through the human body. This technology extends the applicable range of frequency enhancement processing and is combined with granularity improvement technology[9]. It has been reported that DV improves visibility of the entire subject and reduces the frequency of image density and contrast corrections, thus reducing the effort required for image adjustment[9].

We investigated the performance of plain radiography utilizing DV in diagnosing bone metastases.

Materials and Methods

This study was approved by our Institutional Review Boards (No. 29-02-904) and was conducted in accordance with the principles of the Declaration of Helsinki. A retrospective review of patients with pelvic bone metastases was undertaken using medical records and images kept at our hospitals. For patients suspected of having bone metastases within a few weeks of their first visit between April 2018 and March 2021, the original data from plain radiographs obtained at the time of the first visit were preserved for this study. Of the 30 consecutive patients with pelvic bone metastases for whom original image data were extant, 29 patients were included in the present study and one patient with intertrabecular bone metastases was excluded. The flat-panel detector systems used were the CALNEO C1717 Wireless SQ and CALNEO C1417 Wireless SQ (pixel size 0.15 mm, Fujifilm). The image processing unit used was the Console Advance DR-ID 300 (Fujifilm), and the radiography generators used were the RADspeed Safire (Shimadzu) and Radnext80 (Hitachi).

The images were created by processing the original plain radiography data with the default DV settings (Presets 1-4). The features of each preset are as follows:

Preset 1: Image created by interpreting conventional film parameters;

Preset 2: Image visualized using dynamic range compression with the same amount of edge enhancement as Preset 1;

Preset 3: Image with stronger low-frequency enhancement than Preset 2;

Preset 4: Image with overall density flattened and tissue contrast increased by edge enhancement.

These images were imported into PowerPoint (Microsoft). A total of 116 images were created by arranging two images of one patient from different directions on one page (two patients were in one direction only). The 116 images were randomly rearranged to form the evaluation image set (**Fig. 1**). A portable device (iPad Pro 3rd Gen, Apple Japan, Tokyo, Japan) was used as a monitor for image reading. The device had a pixel density of 264 dpi at a resolution of 2,732×2,048 pixels and a screen size of 12.9 inches.

The readers were six orthopedic trainees, and reading time was 30 seconds per image. The only information given during image reading was patient age, sex, and chief complaint (**Fig. 1**). The readers were given the following explanation: "Not all patients have bone metastatic lesions." The readers were not allowed to adjust the window or zoom in on the image. When bone metastasis was suspected, readers were asked to indicate the site of bone metastasis on an illustration of the pelvis on the answer sheet. They were also asked to classify their level of suspicion as 1: strong suspicion of bone metastasis, 2: suspicion of bone metastasis, 3: equal possibility of bone metastasis and non-bone metastasis, and 4: greater suspicion of non-bone metastasis.

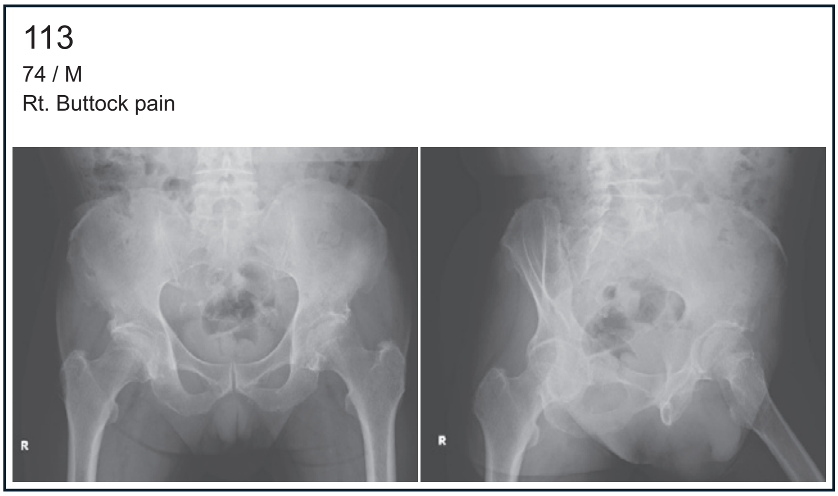

Fig. 1 An example of an evaluation image. A 74-year-old man with pain in the right buttock had metastasis of colon cancer to the right ischial bone.

Table 1 Correct answer rates for the presets (Friedman test)

	Preset 1	Preset 2	Preset 3	Preset 4	*p*
Rate	28.7% (50/174)	34.5% (60/174)	43.7% (76/174)[a]	42.5% (74/174)[b]	<0.001

[a, b]Significant difference from Preset 1 ([a]$p<0.001$, [b]$p = 0.003$, Scheffe correction)

If the indicated site was correct, options 1-3 for the degree of suspicion were scored as correct and option 4 was scored as incorrect. If the indicated site was incorrect or if bone metastasis was not suspected, the answer was scored as incorrect. If there were multiple lesions, the answer was considered correct if the answer indicated the main lesion. The correct answer rate for reading images processed with Preset 1 was compared with the rates for the other presets. Similar comparisons were performed after excluding patients with pathologic fractures.

In addition, we compared the correct answer rate for Preset 1 and the other presets by age (>73 years vs <73 years), sex, site (sacrum vs innominate bone), type of bone metastasis (osteolytic, osteoblastic, mixed), and body mass index (BMI; normal weight, underweight, overweight). The type of bone metastasis was determined based on plain radiography and/or CT scanning.

Statistical Analysis

The Friedman test, followed by the Scheffe test, was used to identify significant differences in the correct answer rates for the four presets. All statistical analyses were performed with Excel statistical software package BellCurve for Excel, ver. 2.15, 2017 (Social Survey Research Information Co., Ltd., Tokyo, Japan). A P value of <0.05 was considered significant.

Results

The average age of the patients was 69.3 years (range 43-89), and there were 18 men and 11 women. The main lesion sites were the acetabulum in 13 patients, the ilium in 7 patients, the sacrum in 7 patients, and the ischium in 2 patients. The type of bone metastasis was osteolytic in 25 patients, osteoblastic in 3 patients, and mixed in 1 patient. The mean BMI was 21.2 (range 14.8-30.0): 15 were of normal weight, 9 were underweight, and 5 were overweight. Pathological fractures were diagnosed in 6 patients. The primary cancers were lung cancer in 11 patients, prostate cancer in 4, breast cancer in 3, kidney cancer in 2, bladder cancer in 2, colon cancer in 2, thyroid cancer in 2, liver cancer in 1, ureteral cancer in 1, and malignant lymphoma in 1.

There was a significant difference in the correct answer rate among the presets (**Table 1**). The correct answer rate was significantly higher for Preset 3 (43.7%) and Preset 4 (42.5%) than for Preset 1 (28.7%) (**Table 1**). The results were similar for the 23 patients without pathological fracture (**Table 2**). In patients aged 73 years or older, men, patients with innominate bone lesions, patients with osteolytic bone metastasis, and those with a normal body weight, the correct answer rate was significantly higher for Presets 3 and 4 than for Preset 1 (**Table 3**). In patients with osteoblastic bone metastasis, the correct answer rate

Table 2 Correct answer rates for the presets after excluding patients with pathological fractures (Friedman test)

	Preset 1	Preset 2	Preset 3	Preset 4	p
Rate	26.0% (36/138)	31.2% (43/138)	40.6% (56/138)[a]	38.4% (53/138)[b]	0.001

[a,b]Significant difference from Preset 1 ([a]p = 0.0059, [b]p = 0.028, Scheffe correction)

Table 3 Correct answer rates for the presets, in relation to clinical factors (Friedman test)

	Preset 1	Preset 2	Preset 3	Preset 4	p
Age, y					
≤72 (84)	25.0% (21/84)	27.3% (23/84)	34.5% (29/84)	34.5% (29/84)	0.106
≥73 (90)	32.2% (29/90)	41.1% (37/90)	52.2% (47/90)[a]	50.0% (45/90)[b]	<0.001
Sex					
Male (108)	31.4% (34/108)	42.6% (46/108)	53.7% (58/108)[c]	46.3% (50/108)[d]	<0.001
Female (66)	24.2% (16/66)	21.2% (14/66)	27.3% (18/66)	36.4% (24/66)	0.058
Site					
Innominate bone (132)	26.5% (35/132)	35.6% (47/132)	46.2% (61/132)[e]	45.5% (60/132)[f]	<0.001
Sacrum (42)	35.7% (15/42)	31.0% (13/42)	35.7% (15/42)	33.3% (14/42)	0.891
Bone metastasis type					
Osteolytic (150)	23.3% (35/150)	28.0% (42/150)	36.7% (55/150)[g]	35.3% (53/150)[h]	0.001
Osteoblastic (18)	55.6% (10/18)	66.7% (12/18)	88.9% (16/18)[i]	83.3% (15/18)	0.018
Mixed (6)	83.3% (5/6)	100% (6/6)	83.3% (5/6)	100% (6/6)	0.572
BMI					
Normal (90)	22.2% (20/90)	28.9% (26/90)	41.1% (37/90)[j]	37.8% (34/90)[k]	0.001
Underweight (54)	29.6% (16/54)	31.5% (17/54)	42.6% (23/54)	40.7% (22/54)	0.112
Overweight (30)	46.7% (14/30)	56.7% (17/30)	53.3% (16/30)	60.0% (18/30)	0.417

[a-k]Significant difference from Preset 1 ([a]p = 0.004, [b]p = 0.016, [c]p<0.001, [d]p = 0.021, [e]p<0.001, [f]p<0.001, [g]p = 0.011, [h]p = 0.029, [i]p = 0.046, [j]p = 0.005, [k]p = 0.035, Scheffe correction)

was significantly higher for Preset 3 than for Preset 1 (**Table 3**). Representative images created using Presets 1-4 are shown in **Figure 2**. **Figure 3** shows imaging findings of other modalities that were used to determine lesion site and type of bone metastasis.

Discussion

The most important finding of this study was that the correct answer rate was significantly higher for images processed with DV Presets 3 and 4 than for Preset 1, which was used to simulate conventional imaging methods. A similar result was obtained even when lesions with pathological fractures were excluded. Preset 3, which yielded the highest correct answer rate, utilizes DV features such as dynamic range compression and low-frequency-emphasis adjustment. This suggests that the present processing method improves plain radiographic detection of bone metastases. Improving the rate of early diagnosis of bone metastases will help minimize complications. To date, few reports have examined the effect of plain radiography image processing on the diagnosis of bone metastasis.

DV is reported to improve the visibility of even large subject structures by 1) minimizing differences in body shape by introducing three-dimensional structure estimation technology and visualizing the entire subject; 2) performing frequency emphasis processing that optimizes the amount of emphasis, including low-frequency components; and 3) combining DV with graininess improvement technology[9]. Three-dimensional structure estimation was achieved by using machine learning techniques to develop recognition technology for subjects outside the irradiation field, direct radiography areas, bone areas, and metal areas, and by estimating the subject's body thickness and composition[9]. It has been reported that this reduces the frequency of density and contrast corrections, potentially reducing the effort required for image adjustments[9]. The preset can be selected by the operator.

We found no significant difference in the rates of correct answers for Preset 1 and the other presets for patients younger than 73 years, female patients, patients with sacral lesions, patients with mixed bone metastases, underweight patients, and obese patients. Presets 3 and 4 were superior to Preset 1 with respect to clinical factors

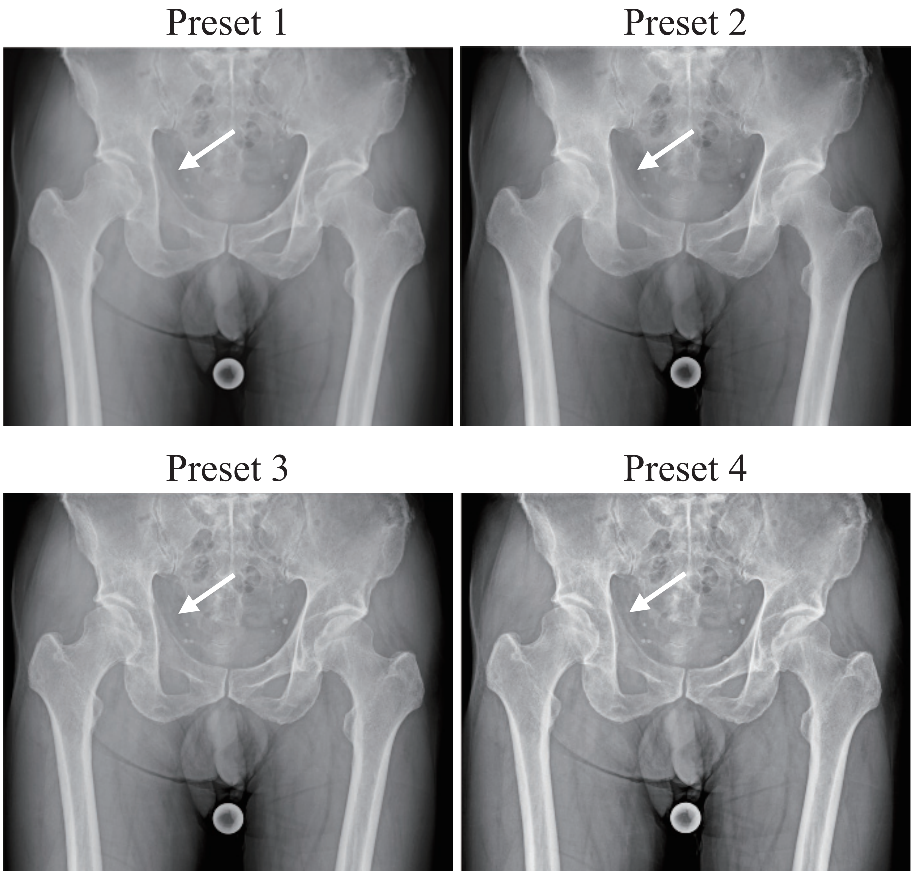

Fig. 2 Representative images created using Presets 1-4. Thinning of the pubic cortex (arrow) is visible in Presets 3 and 4. A 74-year-old man with right groin pain had metastasis of prostate cancer to the right acetabulum and pubic bone.

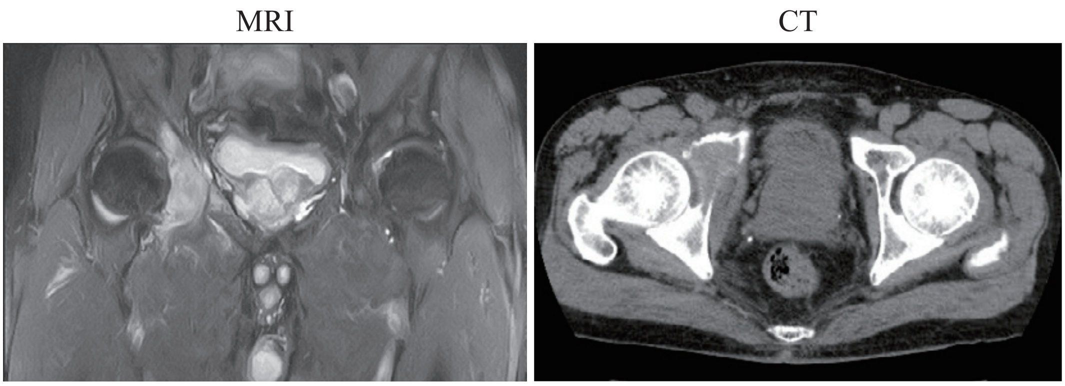

Fig. 3 MRI and CT scans for determining the lesion site and type of bone metastasis.

other than sacral lesions and mixed bone metastases; however, as there was only one patient with mixed bone metastases, it was considered insufficient for evaluation. Possible reasons for the lack of significant differences in sacral lesions include: 1) the fact that pelvic tilt makes it difficult to see the sacral foramen, which allows observation of the sacral cortex, 2) overlap of the sacroiliac joint with the ilium, and 3) presence of intestinal gas and stool. These factors could potentially negate the advantages of image processing.

Regarding the use of plain radiography for diagnosing bone metastases, imaging findings that provide diagnostic clues, such as the pedicle sign[10,11], punched out[12], silhouette sign[13], and asymmetric collapse[14], have been reported. Furthermore, it has been reported that a bone loss of 50-70% is required in order to detect changes in cancellous bone on a plain radiograph[15], that the posterior part of the vertebral body is the most common site for vertebral metastasis[16], and that intertrabecular bone metastases are difficult to depict using plain radiography[17]. Plain radiography has a lower detection rate than bone scintigraphy and CT when screening for bone metastases[18]. However, for symptomatic patients with bone metastases who visit an orthopedic surgeon, plain radiography can detect findings suggesting bone metastasis in about 70% of cases, even at a first consultation[6]. Improving the performance of plain radiography by introducing new image processing software, such as DV, is important because it leads directly to early diagnosis of bone metastases. The diagnostic performance of plain radiography is inferior to that of bone scintigraphy and CT for bone metastases, so it is necessary to understand the advantages and disadvantages of these modalities and use them appropriately.

This study has several limitations. First, for patients with pelvic bone metastases that were discovered much later, plain radiography data at the time of the initial examination may not have been preserved in time to provide images for evaluating various bone metastases. Second, the monitor used for reading the images was 12.9 inches, which was rather small. This may have affected reading results because the conditions were worse than those of actual clinical readings. Third, the target lesions were only in the pelvic bones, so lesions in the spine and proximal femur, where bone metastases are common, will require future study. However, despite these limitations, the present results are of great importance, as they suggest that advances in image processing techniques for plain radiography affect clinical performance.

In conclusion, when reading images processed by DV, the correct answer rate was significantly higher for Presets 3 and 4 than for Preset 1, a simulation of conventional plain radiography. This suggests that image processing by DV improves the ability to diagnose bone metastases on plain radiographs.

Acknowledgements: We would like to express our sincere gratitude to Tsuyoshi Matsumoto and the other radiology staff for their cooperation in collecting image data and for their expert advice.

Conflict of Interest: None declared.

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(Received, July 9, 2024)
(Accepted, September 30, 2024)