—**Case Reports**—

Diagnostic Performance of Advanced Tomosynthesis in Patients with Metal Devices in the Affected Knee: A Case Report

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Simple radiography is the most frequently and widely available technology to examine bone pathologies. Computed tomography (CT) can evaluate pathologies more accurately in multiple planes and three dimensions; however, radiation exposure is much higher than with simple radiography. In addition, diagnostic ability is decreased for both technologies when metal devices are present. Tomosynthesis is a radiographic technology used to evaluate tissues quasi-three-dimensionally with less radiation exposure. Tomosynthesis technology was recently upgraded to reduce the effects of metal artifacts. This case report compares examination time, medical expense, image resolution, and radiation exposure for upgraded tomosynthesis, simple radiography, CT, and standard tomosynthesis in three patients with metal devices in the affected knees. Examination times were similar for the imaging technologies. Diagnostic performance was better for upgraded tomosynthesis than for simple radiography and standard tomosynthesis, and similar to that for CT. Moreover, radiation exposure and expense were higher for tomosynthesis than for simple radiography but lower than for CT. These findings suggest that upgraded tomosynthesis is the best method for evaluating bone pathology when metal devices are present and radiation exposure must be limited. (J Nippon Med Sch 2025; 92: 104–110)

Key words: diagnostic ability, tomosynthesis, metal artifact, radiation exposure, knee pathology

Introduction

Simple radiography is the most frequently used and most widely available technology for examining anatomical morphology and pathology of bone and soft tissue. Because the images are two-dimensional, they must be obtained from multiple directions to ensure diagnostic accuracy and pathological understanding. In comparison, computed tomography (CT) scanning can evaluate target tissues on multiple planes and yields three-dimensional (3D) images after a single scan procedure. However, radiation exposure is much higher for CT than for simple radiography.

Radiation exposure is classified as natural or artificial. Natural radiation originating from the Earth or space poses its own exposure risks. The Nuclear Safety Research Association (NSRA) recommends a maximum total annual effective dose of 2.1 mSv for natural radiation[1]. Artificial radiation is beneficial for people's lives and is used in medicine, pharmacy, engineering, and agriculture. Artificial radiation was reported to be 3.87 mSv in Japan, as compared with the global average annual medical exposure of 0.60 mSv. One reason is that CT examinations are more frequently ordered in Japan than in other countries, as the country has the highest number of CT scanners per person in the world[2].

Radiation exposure-associated complications are classified as deterministic or stochastic. The deterministic effect, which involves skin erythema, hematopoietic damage, fibrosis, and cataracts, is observed after achieving a high threshold dose. These side effects have a much greater threshold dose than the exposure in each diagnostic imaging. Thus, these side effects can be prevented by carefully considering and avoiding cumulative exposure by repeated clinical examinations. Even low-dose radiation exposure without a threshold can have a stochastic effect, leading to DNA damage and carcinogenesis. A

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https://doi.org/10.1272/jnms.JNMS.2025_92-101
Journal Website (https://www.nms.ac.jp/sh/jnms/)

1 Sv (1,000 mSv) effective dose is commonly recognized to increase the risk of cancer-related death by 5%[3]. Hence, although medical radiation exposure is not strictly limited, radiation exposure is kept as low as reasonably achievable (ALARA), considering the necessity of understanding radiological procedures.

Like CT, digital tomosynthesis is a radiographical technique that uses a special reconstruction algorithm and a moving X-ray tube and digital display to evaluate different tissue depths. Tomosynthesis, like simple radiography, yields two-dimensional images but is considered a quasi-3D imaging technique that provides substantial information, akin to full 3D-CT imaging, with lower radial exposure than CT[4,5]. Image resolution is generally lower for tomosynthesis than for CT, and diagnostic performance might be decreased when metal devices are near the critical artifact. However, the diagnostic accuracy of tomosynthesis in the presence of metal devices has been confirmed in a comparison with simple radiography and CT[6-8]. Moreover, tomosynthesis image resolution has been improved with the upgraded T-smart Pro software (Tomosynthesis-Shimadzu Metal Artifact Reduction Technology Pro, Shimadzu Corp., Kyoto, Japan). Tomosynthesis was reported to be a beneficial choice due to its cost-effectiveness[9]. In light of these characteristics, we compared medical expense, image resolution, and radiation exposure of upgraded tomosynthesis with simple radiography, CT, and standard tomosynthesis in three patients with metal devices in their knees.

Patients and Methods

Case 1 (**Fig. 1**): A 66-year-old woman underwent operative fixation for a commuted patellar fracture at another hospital 1 year previously. We evaluated callus formation and bone union.

Case 2 (**Fig. 2**): A 74-year-old man underwent closed-wedge high tibial osteotomy at age 59 years (**Fig. 2-1**). Knee osteoarthritis subsequently developed, and he simultaneously underwent surgery to remove the metal device and total knee arthroplasty (TKA) at our institution. Bone formation at the removal sites and prostheses fixation of TKA were evaluated postoperatively.

Case 3 (**Fig. 3**): An 82-year-old woman who fell and landed on the affected knee 2 weeks after TKA complained of anterior knee pain. Thus, the presence of implant breakage and bone fracture were examined.

For these cases, simple radiographical examinations were performed from two directions, i.e., anteroposterior and lateral views of one knee (RAD Speed Pro, Shimadzu Corp., Kyoto, Japan, RAD NEXT80, FUJIFILM, Tokyo, Japan). Knee CT scans were also performed using a high-resolution CT scanner (Revolution CT, GE HealthCare, Chicago, IL, USA, SCENARIA View, FUJIFILM, Tokyo, Japan). An extended-scale technique was used to suppress the metal artifact. Scans were taken with the settings 120 kV, 400 mA/s, and 500 ms spiral-0.5 mm slice, and a reconstruction interval with axial images of 0.5 mm, after which coronal and sagittal slices were created.

A fully digital diagnostic table with a direct-conversion flat panel detector was used (SONIALVISION safire17; Shimadzu Corp., Kyoto, Japan) for digital tomosynthesis. A fixed X-ray condition (140 kV, 320 mA, 20 ms) was used to acquire 74 frames at a rate of 30 frames/s. An automatic reconstruction algorithm was used to transform these linear scans into CT images with 40° rotation. Projection images were separated into metal images and metal-free images, followed by creation of metal and metal-free reconstruction tomographic images. Finally, these two images were combined. The tomographic images were created automatically.

The T-smart software program (Tomosynthesis-Shimadzu Metal Artifact Reduction Technology, Shimadzu Corp., Kyoto, Japan) was recently upgraded to T-smart Pro (upgraded version). Tomographic images were created with these two versions, and differences in resolution were evaluated.

Calculation of Radiation Exposure Dose

Simple radiography and tomosynthesis

The Surface Does Evaluation Code program (SDEC, S. S. Techno-Engineering Corp., Nagoya, Japan) was used to estimate the entrance surface dose (D) of diagnostic X-rays, in accordance with the calculation method of the Japanese Society of Radiological Technology, as follows:

$D = (X_{air}) \times (1/FSD^2) \times (CF) \times (BSF)$

D is the entrance surface dose (mGy), X_{air} is the exposure dose in air at 1 m from the X-ray tube focus (C/kg), FSD is the focus surface distance (m), CF is the correction factor (mGy・kg/C), and BSF is the backscatter factor.

CT scan

Radimetrics (Byer, Leverkusen, Germany) based on national diagnostic levels in Japan in 2020[10] was used to estimate the entrance surface dose of the CT scan, as follows:

Dose length product (DLP) = CTDIvol × SL

DLP is the dose length product (mGy・cm), CTDIvol is the CT dose index volume (mGy), and SL is the scan length (cm).

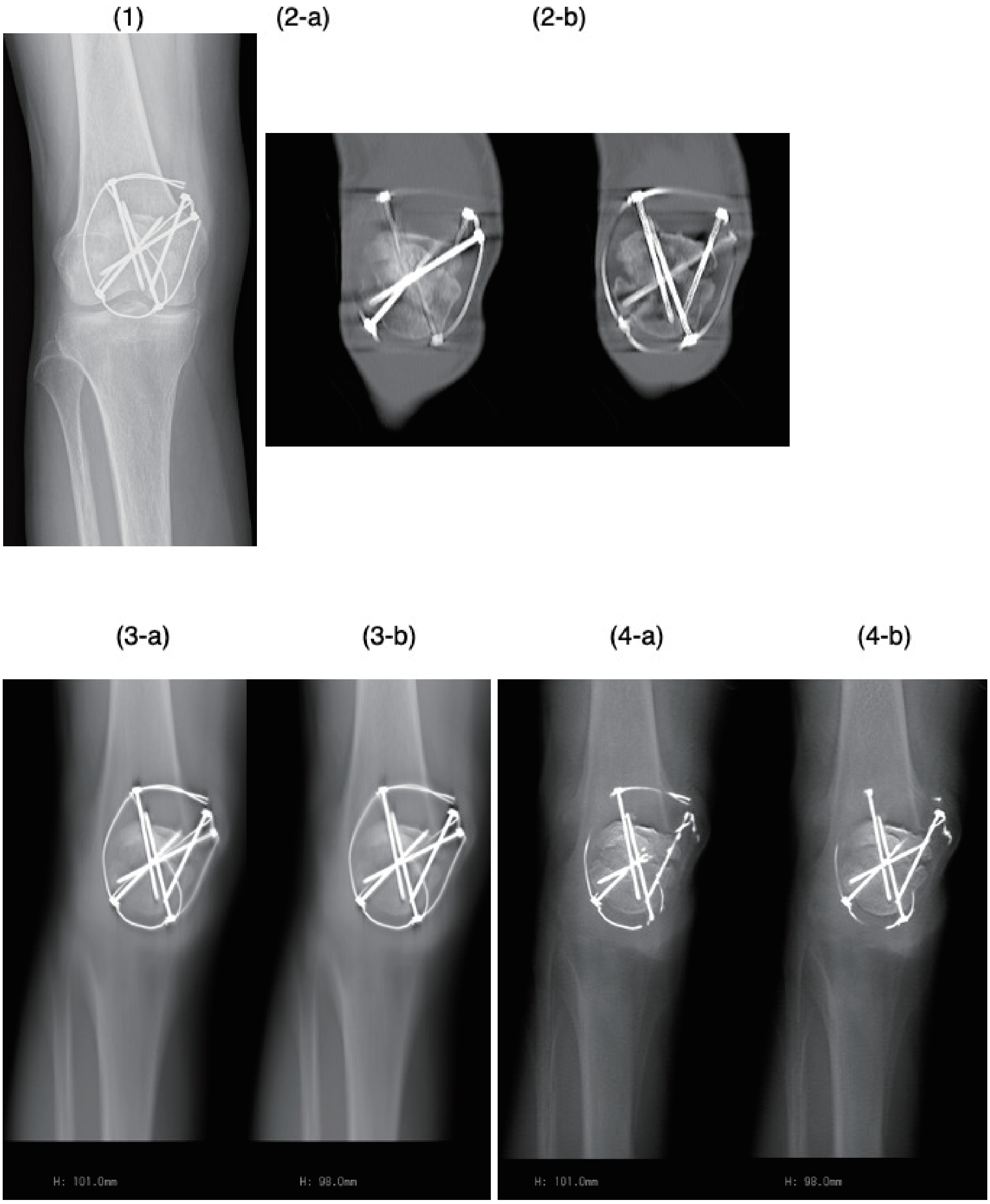

Fig. 1 Case 1: Bone union of the patella
(1) Simple radiography, (2) CT scanning, (3) standard tomosynthesis, and (4) upgraded tomosynthesis.
(a) superficial and (b) deep layers of the patella.

Results

Case 1

Bone union at the fixation site was difficult to diagnose via simple radiography because the patella with multiple metal devices overlapped with the distal femur (**Fig. 1-1**). However, a CT scan was useful for evaluating bone condition (**Fig. 1-2**). Although image resolution was fuzzy in standard tomosynthesis (**Fig. 1-3**), upgraded tomosynthesis provided a clear view of the bone, resembling CT (**Fig. 1-4**).

Case 2

The bone condition of the medial tibial cortex was evaluated; however, the lateral side was not clearly visible with simple radiography (**Fig. 2-2**). The medial and lateral tibial cortices were recognized with CT (**Fig. 2-3**). Similarly, the tibial cortex and bone-prosthesis interface were clearly detected with standard tomosynthesis (**Fig. 2-4, 5**). However, upgraded tomosynthesis was more detailed than standard tomosynthesis.

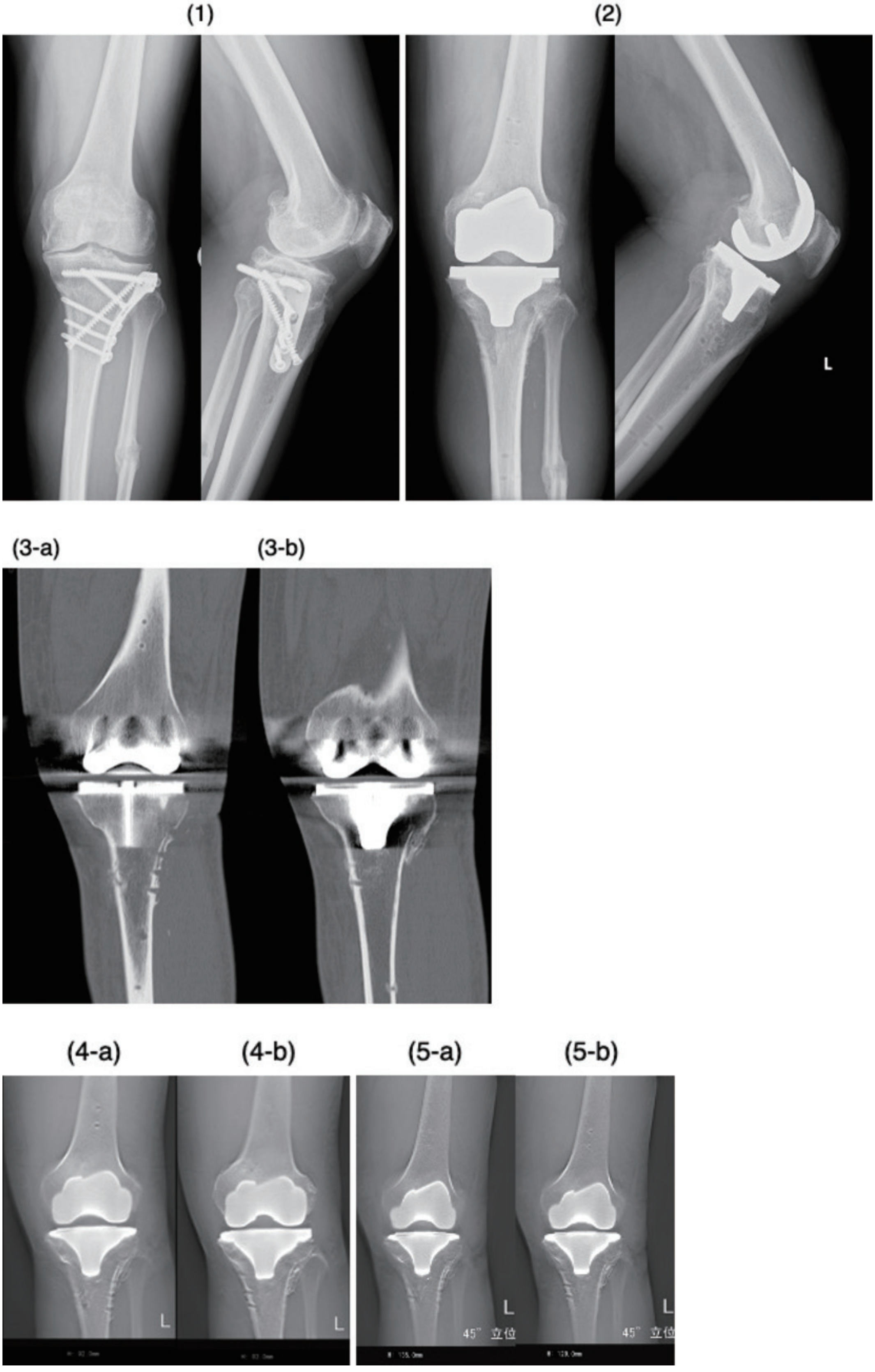

Fig. 2 Case 2: Bone union after surgery
(1) Simple radiography before removal of metal devices, (2) postoperative simple radiography, (3) postoperative CT scanning, including (a) superficial and (b) deep layers of the patella, (4) standard and (5) upgraded tomosynthesis , including the (a) superficial and (b) deep layers of the tibia.

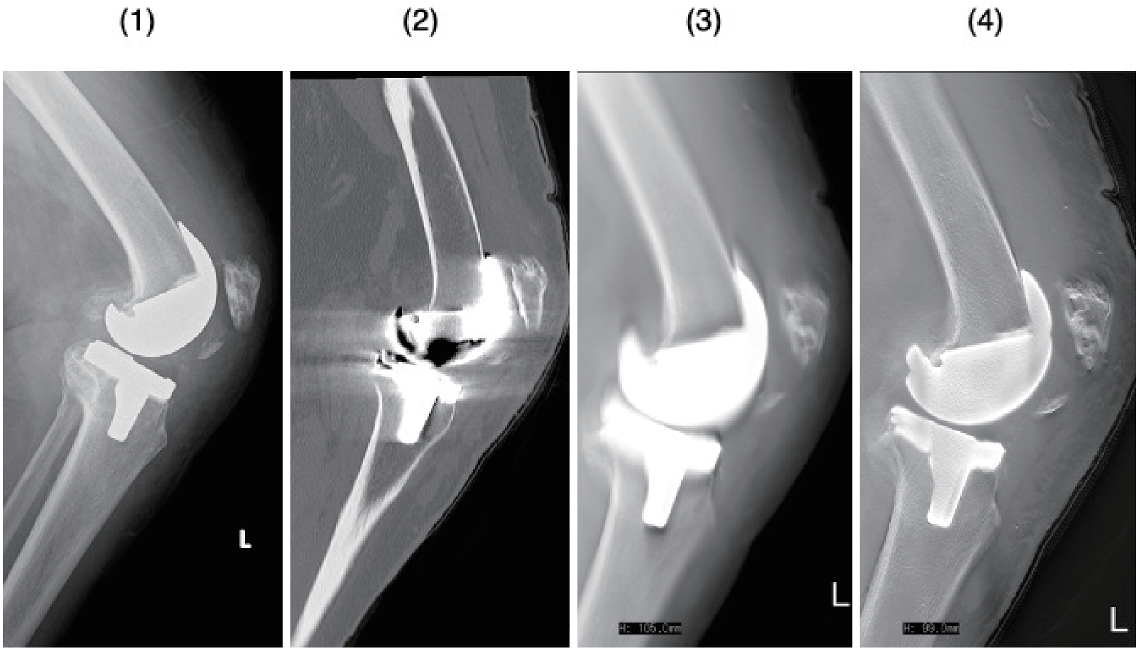

Fig. 3 Case 3: Detection of patellar fracture after TKA
(1) Simple radiography after TKA, (2) CT scanning, (3) standard tomosynthesis, and (4) upgraded tomosynthesis.

Case 3

A small bone fragment was detected with simple radiography (**Fig. 3-1**). However, the bone fragment was barely detectable with CT because of the metal artifact (**Fig. 3-2**). In comparison, tomosynthesis clearly detected the bone fragment (**Fig. 3-3, 4**), and the condition of the bone fragment was clearer with upgraded tomosynthesis.

Medical Expenses

In Japan, one medical fee point is billed as 10 Japanese yen. However, the copayment is less than the full fee and depends on the patient's insurance. When calculating medical fees, the points charged differ slightly by imaging site, the number of images required, and the pathological condition. However, the fee for a simple radiography exam involving two directions of one knee is approximately 224 points. A CT scan is usually approximately 1,570 points and 1,910 points in some cases. In comparison, tomosynthesis is approximately 424 points. Thus, tomosynthesis is slightly more expensive than simple radiography but much cheaper than a CT scan.

Examination Time

Obtaining radiographs for two directions of one knee with simple radiography required approximately 5 min, and the images were created in approximately 7-10 min in the three cases. Obtaining radiographs for a CT scan required approximately 10 min, and creating the images and reconstructing the coronal and sagittal images required approximately 12-17 min. Obtaining tomosynthesis images took approximately 12-28 min, and creating images and reconstructing the coronal images took approximately 5-24 min.

Radiation Exposure

In simple radiography, the tube voltage was set to 66 kV, the tube current to 320 mA, and the exposure time to 0.02 s for one direction of one knee, with a film size of 30.5 cm × 25.4 cm. The FSD was 1.05 m. The Xair, CF, and BSF were calculated as 5.72×10^{-6} C/kg, 31.70 mGy・kg/C, and 1.383, respectively, in the SDEC program. Consequently, the D for two directions of one knee was approximately 0.46 mGy in simple radiography.

In tomosynthesis, the tube voltage was set to 70 kV, the tube current to 250 mA, and the exposure time to 0.05 s for a single exposure of the knee, with a film size of 30.5 cm × 25.4 cm. The FSD was 0.95 m. The Xair, CF, and BSF were calculated as 1.27×10^{-5} C/kg, 31.78 mGy・kg/C, and 1.395, respectively, in the SDEC program. The exposure dose was calculated as 0.63 mGy in one exposure. Tomosynthesis images were reconstructed with 76 exposures; thus, the exposure dose was estimated as 47.88 mGy.

For CT scans, the median CTDIvol was 4.4 mGy and the median SL was 30.5 cm and the film size was 30 cm × 30 cm; thus, the DLP was estimated at 134 mGy・cm.

Discussion

Tomosynthesis, simple radiography, and CT scanning were used to evaluate three conditions in knees with metal devices. Upgraded tomosynthesis had better bone image resolution than simple radiography and standard tomosynthesis and similar resolution to CT. Medical expenses and radiation exposure were lower for tomosynthesis than for CT.

Musculoskeletal tissue pathologies were accurately evaluated with CT; however, image resolution of the region of interest was diminished by the presence of metal devices. Radiation exposure is the principal disadvantage of CT. Radiation exposure for a simple radiograph of the frontal chest was 0.03 mSv, and for the four directions of the lumbar spine, it was 0.8 mSv. The effective dose for head, chest, and chest to pelvis CT scans was 2.5 mSv, 6 mSv, and 14 mSv, respectively. Therefore, repeat CT examinations should be cautiously and systematically performed[11].

Tomosynthesis is commonly used for chest and breast pathology evaluations and was also reported useful in diagnosing musculoskeletal tissue pathologies[12,13]. Tomosynthesis has benefits in addition to image resolution, such as lower cost and less radiation exposure than CT scans[14]. The time required to obtain images depends on the number of images needed; however, examination duration was similar for the three procedures. Reconstruction procedures to create images also depend on the experience of the radiologists; however, the time for tomosynthesis and CT scans did not differ.

The present results indicate that the exposure dose for tomosynthesis was one-half to one-third that of CT scans but was much higher than that of simple radiography. Conversely, the radiation dose of tomosynthesis was less than 1/10 that of CT and 2-3 times that of simple radiography[15,16]. Because examination devices, conditions, image resolutions, and calculation methods vary among studies, it is difficult to compare radiation doses directly. In our study, the doses for tomosynthesis and CT were higher than in other studies. The exposure dose can be reduced to prevent radiation exposure-related complications; however, image resolution tends to decrease as the X-ray dose decreases, especially in target tissues with metal devices. It reduces diagnostic accuracy; therefore, it is necessary to establish the optimal balance between exposure dose and diagnostic performance when using upgraded tomosynthesis.

This study has limitations. The number of patients was small, and only three pathological conditions were evaluated. Radiation exposure, examination time, and examination expenses were approximations. These results may be different for other cases, institutions, and countries. Therefore, future studies should investigate other pathological conditions.

In conclusion, upgraded tomosynthesis may prove to be the optimal procedure for limiting radiation exposure and evaluating bone pathology in patients with metal devices.

Acknowledgements: We thank Kazuya Takahashi and the radiologists in the department of Radiology at Nippon Medical School for the examinations of the patients and advice on calculating radiation exposure.

Conflict of Interest: None declared.

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(Received, September 20, 2023)
(Accepted, October 25, 2023)
(J-STAGE Advance Publication, June 18, 2024)