INNERVISION
Vol. 25, No. 8 (Series No. 293)
Extract from the issue of Aug., 2010

Special Report

Evening Seminar at the 83rd Annual Meeting of the Japanese Orthopaedic Association

Clinical Applications to Orthopaedics by New X-ray Technology

Shimadzu's Tomosynthesis, Slot Radiography and Dual Energy Subtraction by direct conversion FPD

— Imaging technique and clinical application to orthopaedics

Takatoshi AOKI
Associate Professor, Department of Radiology, University of Occupational and Environmental Health

Utility of Tomosynthesis and Slot Radiography to Orthopaedics

Hiroyuki TSUCHIYA
Professor and Chairman, Department of Restorative Medicine of Neuro-Musculoskeletal System (Orthopaedic Surgery), Kanazawa University Graduate School of Medical Science

Shimadzu Corporation

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Clinical Applications to Orthopaedics by New X-ray Technology

At the 83rd Annual Meeting of the Japanese Orthopaedic Association held between Thursday, 27 May, and Sunday, 30 May, Shimadzu co-hosted Evening Seminar on the theme of "Clinical Applications to Orthopaedics by New X-ray Technology" on 29 May. The Seminar was chaired by Akinori SAKAI, M.D., Associate Professor, Department of Orthopaedic Surgery, University of Occupational and Environmental Health. Lectures were given by Takatoshi AOKI, M.D., Associate Professor, Department of Radiology, University of Occupational and Environmental Health, entitled "Shimadzu' s Tomosynthesis, Slot Radiography and Dual Energy Subtraction by direct conversion FPD – Imaging technique and clinical application to orthopaedics" and by Hiroyuki TSUCHIYA, M.D., Professor, Department of Restorative Medicine of Neuro-Musculoskeletal System, Kanazawa University Graduate School of Medical Science, entitled "Utility of Tomosynthesis and Slot Radiography to Orthopaedics."

Chairman
Akinori SAKAI, M.D.
Associate Professor, Department of Orthopaedic Surgery, University of Occupational and Environmental Health

Shimadzu's Tomosynthesis, Slot Radiography and Dual Energy Subtraction by direct conversion FPD

—Imaging technique and clinical application to orthopaedics

Takatoshi AOKI, M.D.
Associate Professor, Department of Radiology, University of Occupational and Environmental Health

The SONIALVISION safire with a 17 × 17-inch direct-conversion flat panel detector (FPD) in operation at this hospital offers extremely high-resolution images with a large field of view and distortion-free. This lecture covered the principles and features of three technologies incorporated into SONIALVISION safire – tomosynthesis, slot radiography, and dual energy subtraction–and reports on their utility and feasibility in the field of orthopaedics.

Advantages of Flat Panel Detectors

In comparison with the conventional image intensifier (I.I.), the flat panel detector (FPD) offers high quality image with a large field of view and distortion-free. In addition, the high sensitivity permits imaging with low dose exposure. The images can be routinely observed in realtime. FPDs adopt two methods to convert X-rays to electrical signals: direct conversion and indirect conversion.

The indirect-conversion method uses cesium iodide to convert the X-rays to light and then uses photodiodes to convert the light to electrical signals. On the other hand, the direct-conversion method directly converts the X-rays to electrical signals in an amorphous selenium (a-Se) X-ray conversion layer. The Shimadzu SONIALVISION safire in operation at the hospital uses a direct-conversion FPD (**Fig. 1**). The direct-conversion FPD offers sharper images, even in fine detail structures, and superior image resolution to an indirect-conversion detector.

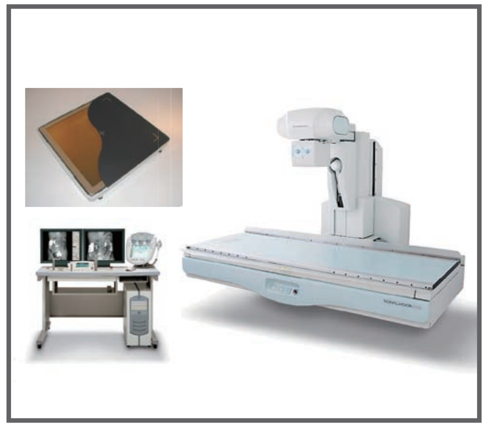

Fig. 1 SONIALVISION safire

Tomosynthesis

Principle and Features

Tomosynthesis is a technology that obtains images on arbitrary parallel cross-sections through image reconstruction of multiple projected images taken by a single exposure. The image reconstruction is based on image reconstruction for cone-beam CT, with additional correction for differences between CT rotation and tomosynthesis parallel-plane scanning, and three-dimensional filtered projection to remedy artifacts due to angular restrictions (Fig. 2).

Its features include: (1) short imaging time about 2.5 or 5 sec, (2) imaging in standing, supine, or tilting postures, (3) extremely high resolution images in parallel plane to the tabletop, (4) minimum metal artifacts, and (5) low dose exposure, approximately twice that of a plain radiography. In particular, the freedom of body posture provides significant merit for orthopaedic examinations.

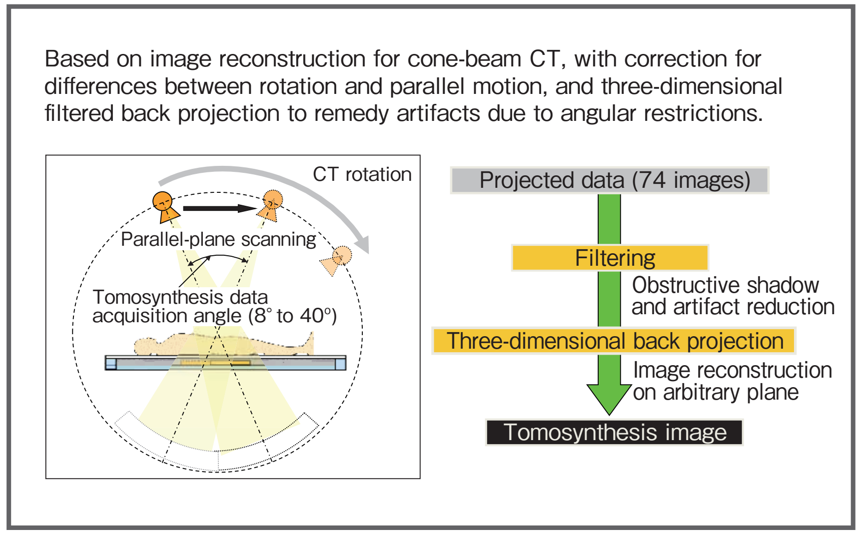

Fig. 2 Principle of Tomosynthesis

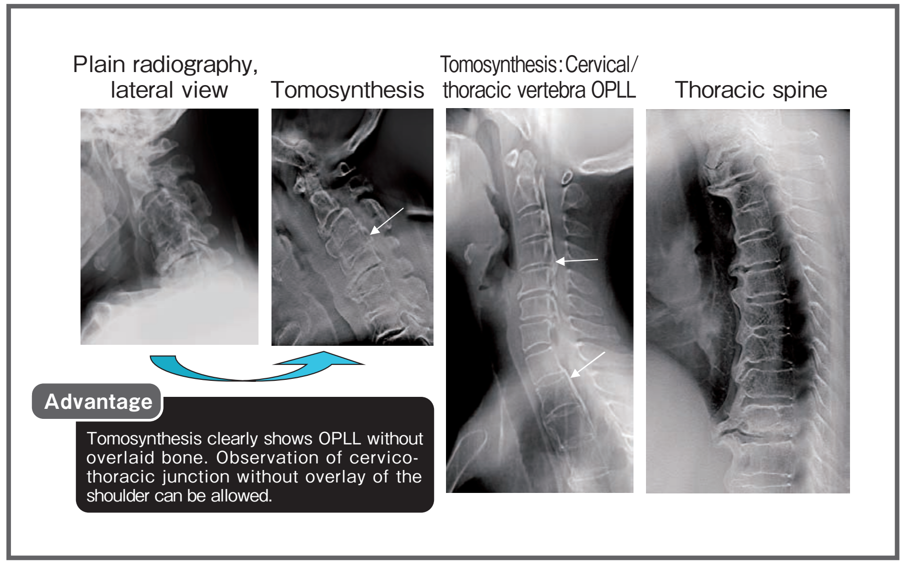

Fig. 3 Ossification of Posterior Longitudinal Ligament (OPLL) of the Cervical / Thoracic Vertebra and Images of Thoracic Spine

Cases

Fig. 3 shows two cases of ossification of posterior longitudinal ligament (OPLL) of the cervical / thoracic vertebra.

Although OPLL can be observed in the plain radiography lateral view, the shoulder is generally overlaid on the cervicothoracic junction in plain radiography images, making evaluation difficult. Conversely, tomosynthesis offers clear images with no overlaid shoulder. The extensive imaging range offers cross-sectional images of the entire thoracic spine.

Fig. 4 shows images taken to observe the bone structure in the femoral component after total knee arthroplasty (TKA). Post-TKA CT observations of the distal femur can often be difficult due to the strong metal artifacts. However, tomosynthesis creates fewer metal artifacts and offers multiple slices showing the structure from the inside to the outside of the distal femur. A fracture around metallic implant is indicated in this case.

Tomosynthesis is often used for cases of rheumatoid arthritis in our hospital. Regions of overlapping bones, such as the carpal bones, can be difficult to observe in plain radiography images, whereas tomosynthesis offers clear images of bone erosion of the carpal bones (Fig. 5). In practice, it feels that the use of tomosynthesis has enhanced the detection of bone erosion.

Comparison of Tomosynthesis, Plain Radiography, and CT

The guidelines for plain radiography in the "2006 Guideline for Medical Exposure" published by the Japan Association of Radiological Technologists were compared with the entrance surface dose of tomosynthesis (Fig. 6). The results shows that the tomosynthesis exposure dose is 1.1 times that of plain radiography for frontal images of the head and hip joints, 2.2 times for the lateral view of the cervical vertebra, and 2 times for the finger or knee joints. It is apparent that tomosynthesis offers the required cross-sectional images with approximately twice the exposure dose of a plain radiography for orthopaedics.

Also, in comparison with CT, tomosynthesis offers the advantages of: (1) low dose exposure; (2) imaging in standing, supine, or tilting postures that supports imaging with loads applied to weight-bearing bones and examinations for sports medicine; (3) limited artifacts from metal implants makes tomosynthesis effective for follow-up observations of looseness of artificial joints, and bone grafts; (4) high examination throughput due to short imaging times; (5) extremely high, 300 μm, resolution for images parallel to the patient table.

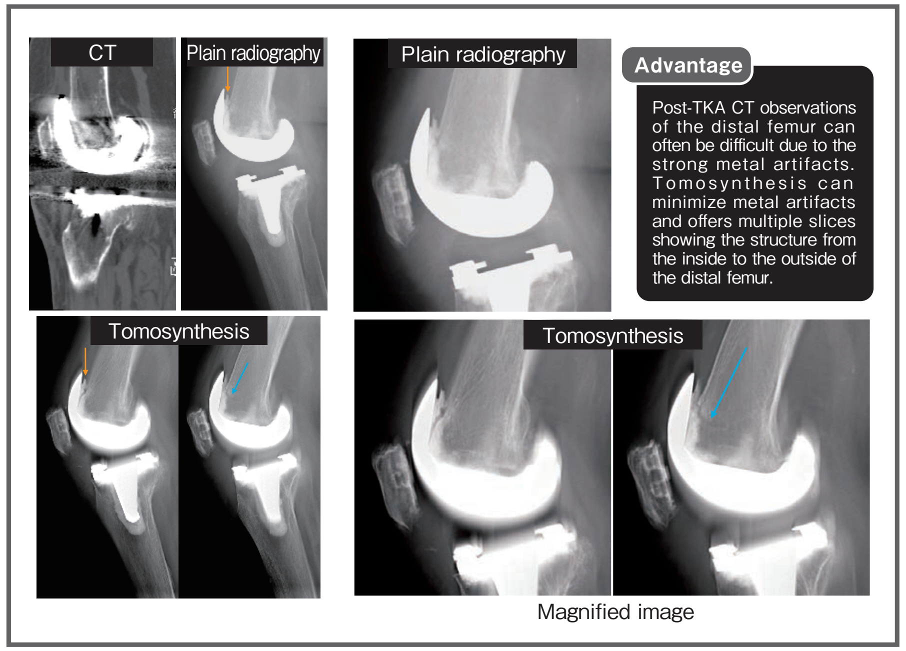

Fig. 4 Post-TKA Bone Structure in Femoral Component
(Images supplied by Hachiya Orthopaedic Hospital)

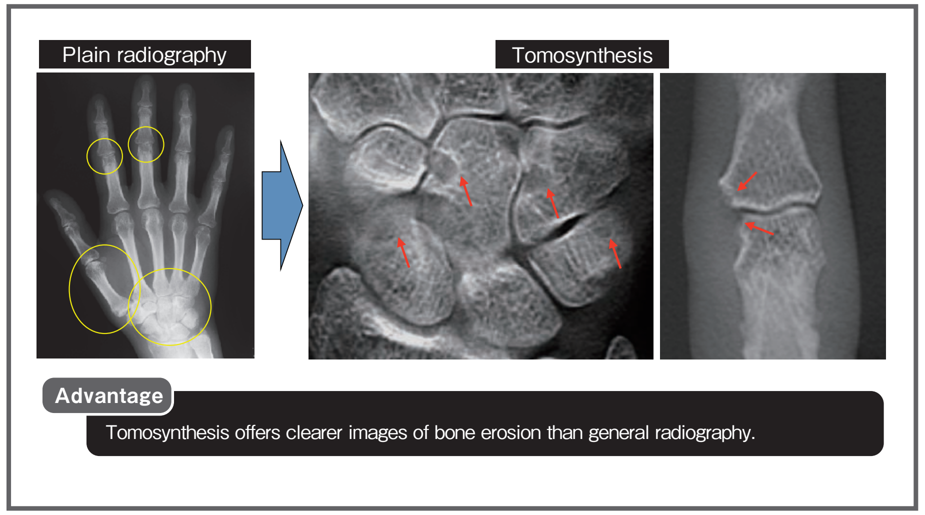

Fig. 5 Cases of Rheumatoid Arthritis

HD Tomosynthesis

Shimadzu is currently developing High-Definition (HD) Tomosynthesis to achieve even higher image resolution. It is expected to visualize finer trabecular bone structures and bone fractures.

Slot Radiography

Slot radiography involves serial pulsed exposures using slot-shaped X-rays with a narrow beam angle. This technology achieves seamless Long-View, for instance the whole spine. Slot images are obtained by stitching the slot-shaped images taken by scanning the synchronized X-ray tube and FPD in the body axis direction. Imaging 90 cm in length takes only 6 to 12 seconds, and the technique supports imaging in the supine position and standing position with the tiltable tabletop. Low image distortion allows highly accurate measurements.

Fig. 7 shows pre and post-TKA slot radiography images in the standing posture with almost no image distortion. Geometric accuracy can be maintained by specifying the height of the area of interest from the tabletop. The X-ray dose is less than one-half that of conventional CR radiography.

Dual Energy Subtraction

Dual energy subtraction (D.E.) is a technology that involves imaging at high voltage and low voltage and performing weighted subtraction of the two images to visualize the dif-

	2006 Guideline for Medical Exposure (Plain Radiography) (A)	Tomosynthesis Entrance Surface Dose (B)	B/A	Tomosynthesis Radiography Conditions Rev. 3.80
Head (frontal)	3mGy	3.2mGy	1.1	85kV, 1.25mAs
Cervical vertebra (lateral)	0.9mGy	2mGy	2.2	75kV, 1.25mAs
Fingers	0.1mGy	0.2mGy	2.0	47kV, 1.25mAs
Knee joint	0.4mGy	0.8mGy	2.0	65kV, 1.25mAs
Hip joint (frontal)	4mGy	4.5mGy	1.1	80kV, 2.5mAs

Advantage

In many orthopaedic areas, tomosynthesis requires approximately twice the exposure dose prescribed in the 2006 Guideline for Medical Exposure for each body part.

Fig. 6 Comparison of 2006 Guideline for Medical Exposure (Plain Radiography) and Tomosynthesis Entrance Surface Dose

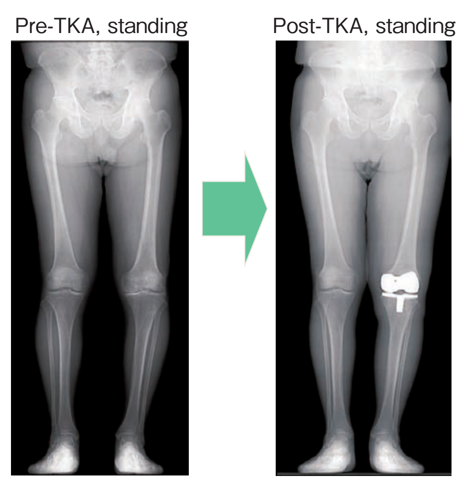

Fig. 7 Pre- / Post-TKA Slot Radiography Images

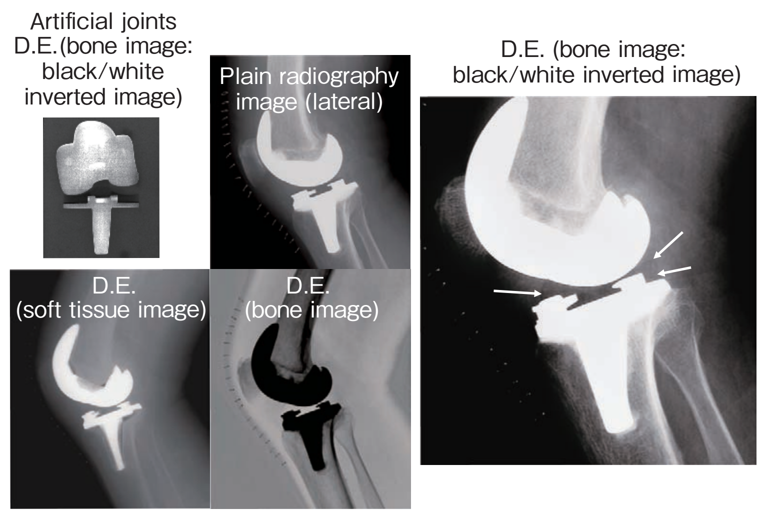

Fig.8 Application of Dual Energy Subtraction (D.E.) : Post-TKA Lateral Views of Knee Joint

ferences in X-ray absorption coefficient. It is able to obtain an only bone image or an only soft-tissue image. The major clinical application of D.E. is in the thoracic region, where it is used to separate the soft-tissue image and the bone image to clearly reveal lung nodules hidden by ribs. In addition, the costicartilage, which is easily mistaken for nodules, can be identified in the bone image. The application of D.E. to orthopaedics is challenging. An application currently under consideration is the observation of polyethylene surfaces in artificial joints. **Fig. 8** shows post-TKA lateral images of knee joint. The polyethylene surfaces that are indistinct in the conventional radiography image are clearly visible in the black/white inverted bone image obtained by dual energy subtraction. This may be useful for evaluation of artificial knee joints evaluation of wear in knee joints.

Conclusions

This lecture discussed the technologies, utility, and feasibility of tomosynthesis, slot radiography, and dual energy subtraction by direct-conversion FPD. I expect further developments of these three technologies in orthopaedics.

(Extract from Evening Seminar "Clinical Applications to Orthopaedics by New X-ray Technology" co-hosted by Shimadzu at the 83rd Annual Meeting of the Japanese Orthopaedic Association, Editorial Department)

About the Author

Graduated School of Medicine, University of Occupational and Environmental Health, in 1989. Resident (clinical intern) in the University Hospital at the University of Occupational and Environmental Health. In 1993, entered the doctoral program, specializing in clinical / biomedical informatics, Graduate School of Medical Science at the University of Occupational and Environmental Health. Completed doctorate in 1997. In 1997, instructor at the Department of Radiology, University of Occupational and Environmental Health. Attained current position from 2008.

Utility of Tomosynthesis and Slot Radiography to Orthopaedics

Hiroyuki TSUCHIYA, M.D.
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Tomosynthesis can create high-resolution tomographic images eliminating of effects from the bones in front and behind. It is little affected by metal artifacts and offers a high degree of flexibility in patient posture, making it an effective technique for orthopaedics. This lecture will report on the application and clinical utility of tomosynthesis in orthopaedics and present images of actual cases. In addition, I will describe our clinical experiences at this hospital with slot radiography, which produces seamless long-view images.

Utility of Tomosynthesis

Tomosynthesis can create multiple images parallel to the patient table from a single tomographic imaging operation. Tomosynthesis makes it easy to take extremely high-resolution images and is little affected by metal artifacts. It requires approximately twice the exposure dose of a plain radiography and one-tenth the dose of a CT scan. Since installing the Shimadzu SONIALVISION safire with a 17 × 17-inch direct-conversion FPD at this hospital, we have actively used its tomosynthesis function.

■ Cases

Fig. 1 shows the follow-up 42 months after curettage and artificial bone graft for osteosarcoma of the pelvis. Tomosynthesis clearly reveals the union between the artificial bone and host bone. Tomosynthesis offers detailed observations of the boundary between the artificial bone and host bone at any cross-section to allow easy evaluation of the bone union.

Fig. 2 shows a case of resection of osteosarcoma of the proximal tibia and grafting of liquid nitrogen-treated bone. CT suffers from strong effects of metal artifacts, whereas tomosynthesis provides extremely clear observations of the affected area that allow evaluation of the state of bone union. **Fig. 3** shows images of grafted liquid nitrogen-treated bone in the proximal femur. While the plain radiography image shows binding at the interface, tomosynthesis clearly reveals that union has not yet occurred.

In **Fig. 4**, the metal, pins, and wires in the plain radiography images hinder evaluation in a case of external fixation. However, although it cannot completely eliminate the effects of the metal, tomosynthesis restricts its effects to reveal the bone status.

1) Evaluation of the boundary conditions of femur osteotomy and RAO

This shows a case of acetabular dysplasia. Due to the good

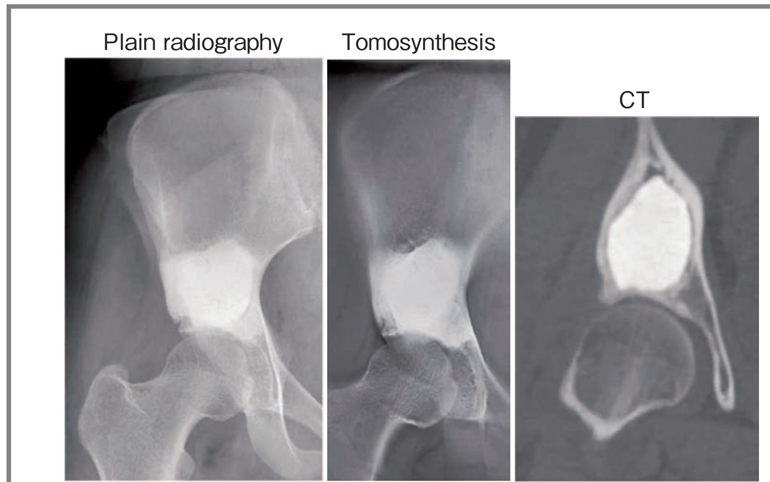

Fig. 1 Artificial Bone Graft (BIOPEX®)

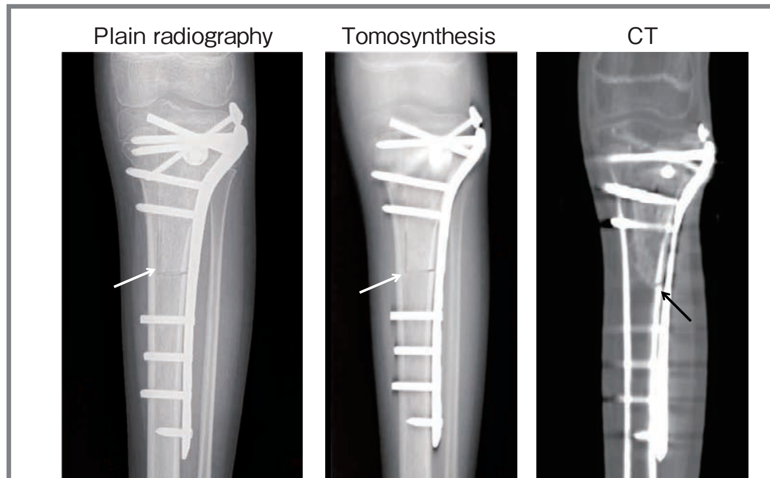

Fig. 2 Evaluation of Bone Union (Reconstruction for Proximal Tibial Osteosarcoma)

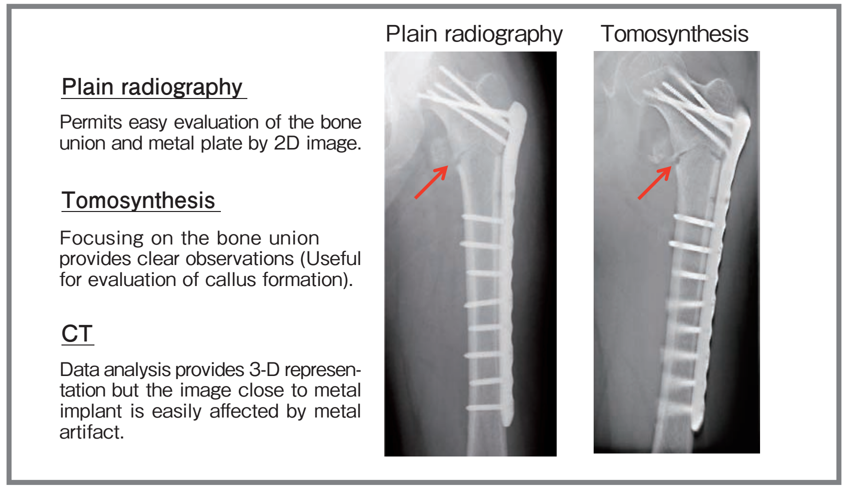

Fig. 3 Images of Proximal Femur

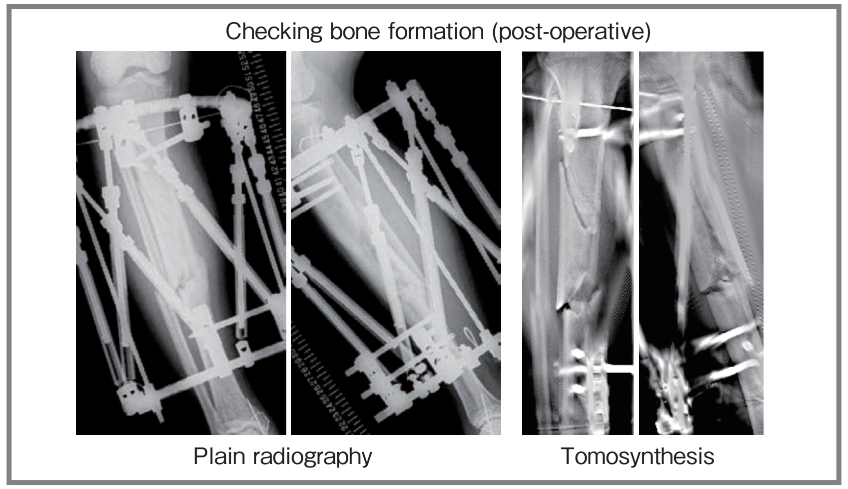

Fig. 4 External Fixation

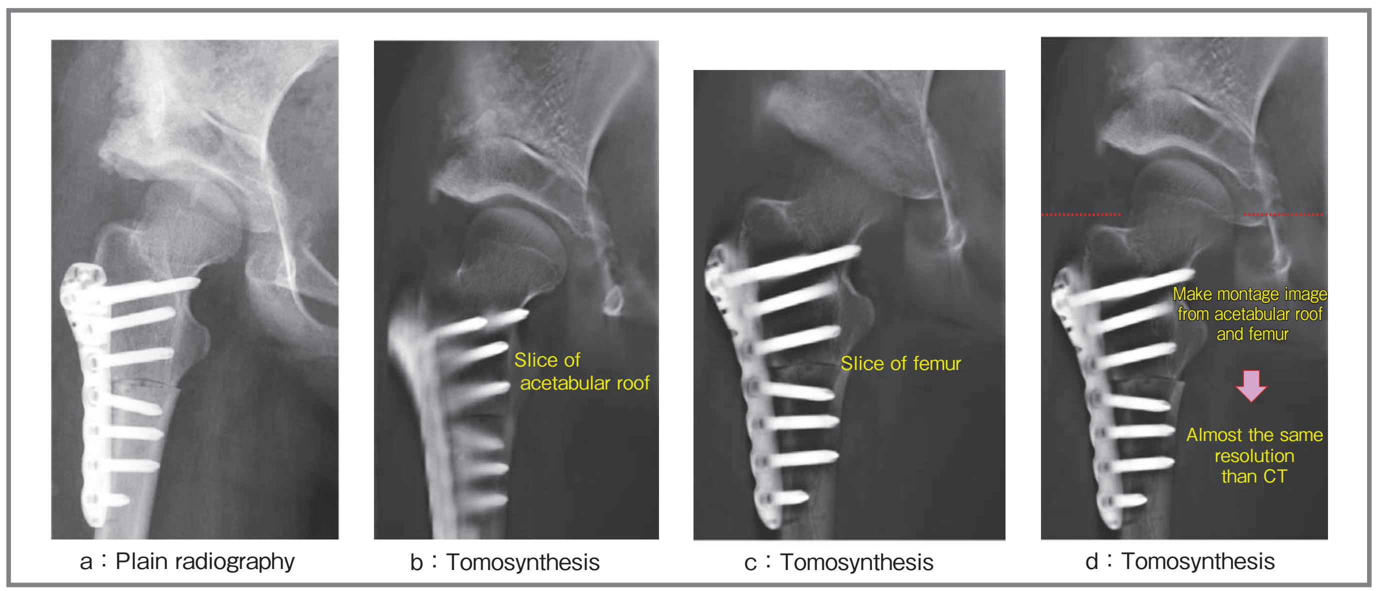

Fig. 5 Evaluation of the boundary conditions of femur osteotomy and RAO

compatibility with the adduction position, rotational acetabular osteotomy (RAO) was performed. After further careful evaluation, derotational osteotomy was also performed due to the strong anteversion of the femoral neck. Fig. 5 shows post-operation plain radiography and tomosynthesis images.

The tomosynthesis images focused on the acetabulum (Fig. 5b) and the femur (Fig. 5c) permit thorough examination of the osteotomy site. Combining the two images focused on the acetabulum and femur yields a high-resolution image (Fig. 5d) that is as good as CT image.

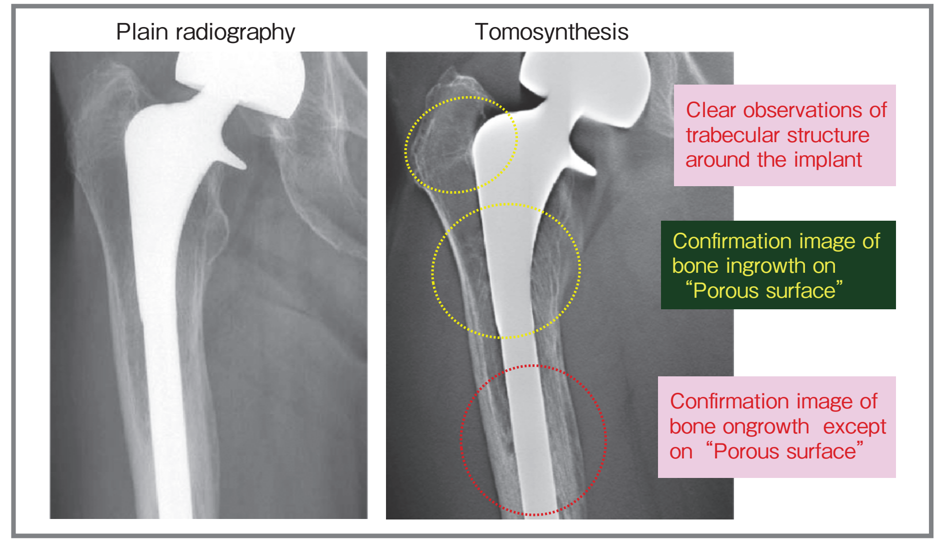

Fig. 6 Evaluation of Bone Ingrowth and Bone ongrowth on the Implant Surfaces

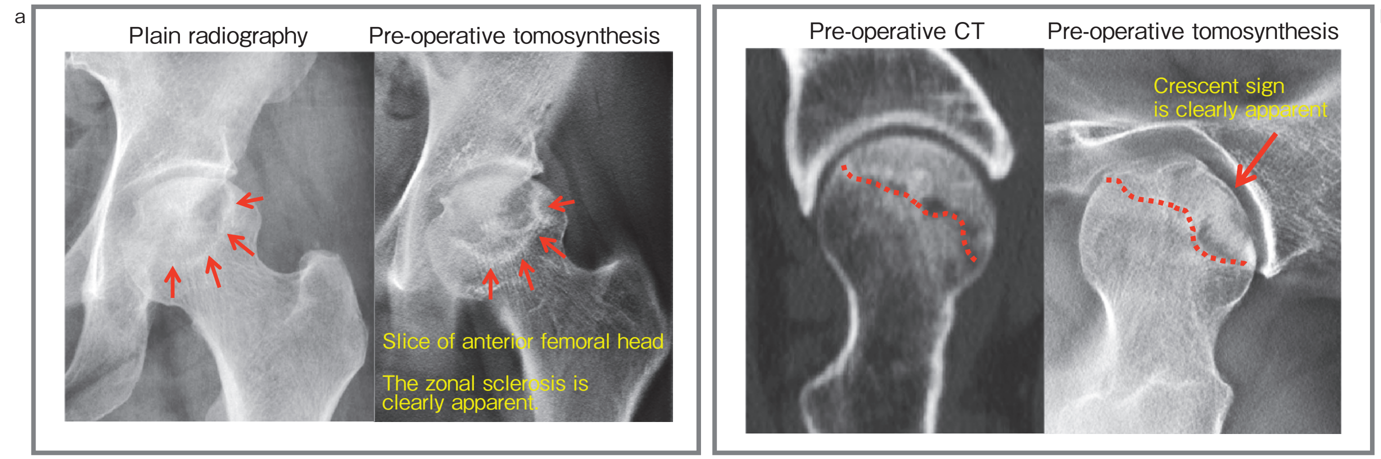

Fig. 7 Evaluation of necrotic regions and crushing conditions of ANFH

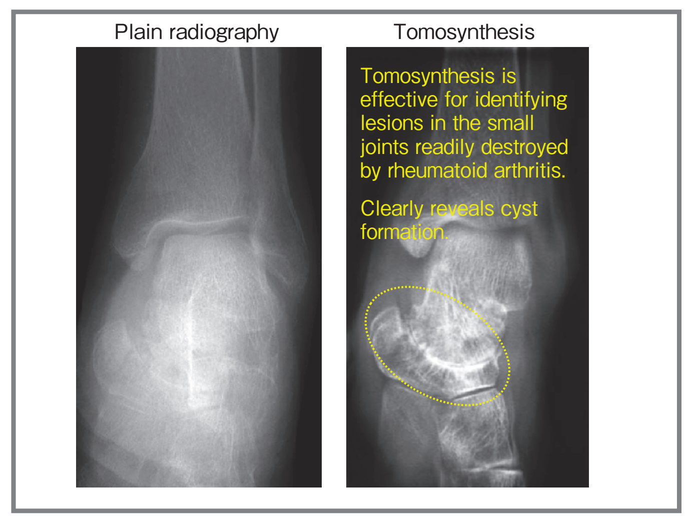

Fig. 8 Bone-Destructive Lesion in Rheumatoid Arthritis

2) Evaluation of the progress of Bone ingrowth and Bone ongrowth on the implant surfaces.

Fig. 6 shows a case 18 years after femoral head replacement. Tomosynthesis clearly reveals the trabecular structure around the implant. The bone ingrowth into the porous surface and bone ongrowth except onto the porous surface can be observed. Tomosynthesis permits convenient evaluations on an out-patient clinic basis.

3) Evaluation of necrotic lesions and crushing conditions of ANFH

Fig. 7a shows pre-operative plain radiography and tomosynthesis images for avascular necrosis of the femoral head.

The tomosynthesis image of the anterior femoral head clearly reveals the zonal sclerosis. It shows the necrotic area and clearly reveals that crushing of the femoral head has occurred. The crescent sign is extremely conspicuous (Fig. 7b).

4) Bone Destruction lesion in rheumatoid arthritis

Fig. 8 shows frontal plain radiography and tomosynthesis images of a bone destruction lesion in rheumatoid arthritis. The destruction of the talonavicular joint is difficult to discern in the plain radiography image due to overlay of the calcaneal bone. Conversely, tomosynthesis clearly shows the cyst formation.

Therefore, tomosynthesis is also effective for identifying lesions in the small joints that are readily destroyed by rheumatoid arthritis.

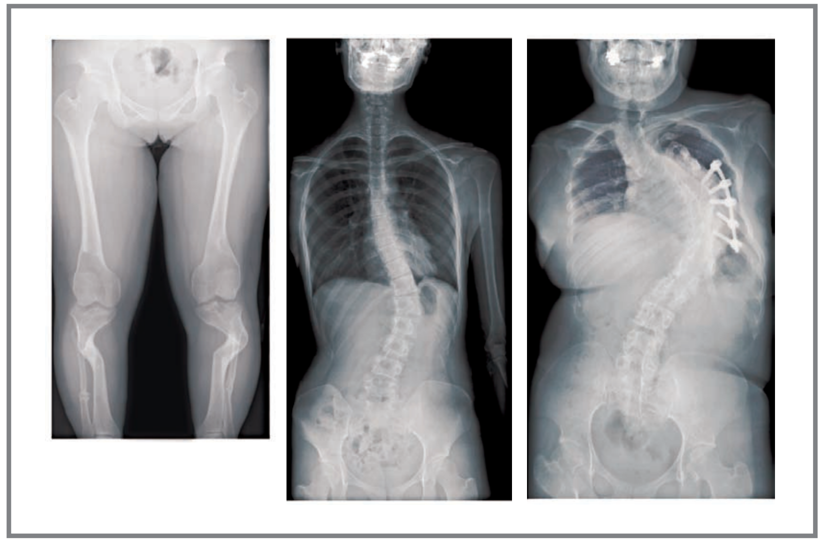

Fig. 9 Slot Radiography Images
After corrective surgery on both legs (left), scoliosis (center, right)

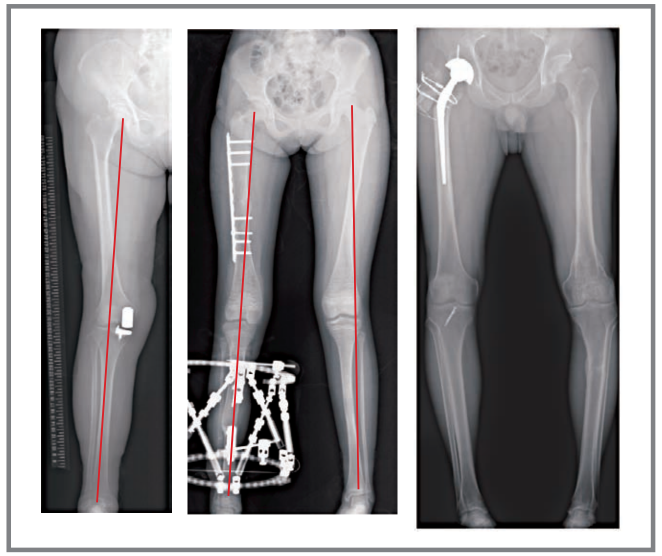

Fig. 10 Evaluation of Alignment of Lower Limbs by Slot Radiography

Utility of Slot Radiography

Slot radiography offered by SONIALVISION safire can easily take seamless slot images to produce frontal or lateral images of the spine or lower extremities more rapidly than conventional CR (**Fig. 9**). At this hospital, slot radiography is mainly used to evaluate alignment of the lower limbs after artificial joint implant surgery or for scoliosis.

Fig. 10 shows the evaluation of the alignment of lower limbs using slot radiography images. Treatment straightened the mechanical axis of the lower limbs to match the inclination of the articular surface. Lower distortion than conventional CR images simplifies evaluation of the disease.

Conclusions

Tomosynthesis permits the evaluation of the interior of bone tumor that is difficult to observe in plain radiography images; offers detailed observations of bone structure, including the state of bone union after osteotomy or fracture; and is extremely easy to use for routine care in the orthopaedics department. As tomosynthesis is little affected by metal artifacts, it can be applied to treatment sites that are difficult to observe by CT and offers observations of the bone status around implants. Moreover, its low exposure dose and high degree of flexibility in patient posture make tomosynthesis an extremely effective technique for us orthopaedic surgeons.

(Extract from Evening Seminar "Clinical Applications to Orthopaedics by New X-ray Technology" co-hosted by Shimadzu at the 83rd Annual Meeting of the Japanese Orthopaedic Association, Editorial Department)

About the Author

Graduated School of Medicine, Kanazawa University, in 1983. In 1983, joined the Department of Orthopaedic Surgery and entered the Graduate School of Medicine at Kanazawa University. Physician, teaching assistant, lecturer in medicine at Kanazawa University Hospital. Overseas training at University of Vienna. From 1994, lecturer in medicine at Kanazawa University Hospital. Associate professor at Faculty of Medicine, Kanazawa University from 1999. From 2006, hospital clinical professor and head of orthopaedic surgery at Kanazawa University Hospital. From 2010, professor and chairman of Department of Restorative Medicine of Neuro-Musculoskeletal System (Orthopaedic Surgery), Kanazawa University Graduate School of Medical Science