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Usefulness of Tomosynthesis for Orthopedics

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1. Introduction

The Chiba Central Medical Center was established as Kasori Hospital in 1987, in the northwest part of Chiba prefecture, as a general hospital with 150 beds. However, to become a more advanced medical institution, a second phase of construction occurred in 1998. Currently, we have grown to become a central hospital for Chiba city, with 272 beds and 26 medical departments. From the beginning, we focused on developing advanced medical capabilities, such as single-photon emission computed tomography (SPECT) and MRI, so in 2004, the hospital name was changed to the Chiba Central Medical Center. At the same time, we introduced an electronic medical patient record system and PACS to switch to digital imaging and migrate to a paperless/filmless operation. Then in September 2010, we introduced the Shimadzu SONIALVISION safire system, equipped with tomosynthesis, which can be used not only for orthopedics, but also a variety of other fields, such as gastrointestinal radiography and venography of lower extremities. The word tomosynthesis combines the words "tomography" and the Greek-origin word "synthesis" and refers to new digital tomography technology that combines computed tomography with digital image processing.

Current radiographic diagnostic imaging is the culmination of developments and improvements to various diagnostic imaging technologies such as CT and MRI. However, in the field of orthopedic surgery, there are still many cases that are difficult to diagnose with such systems. If often occurs that key target points are not represented accurately in cross sectional images and are overlooked due to artifacts from metal implants, complicated anatomical shapes of bones, and so on. Furthermore, previous diagnostic imaging equipment was not suited to capturing changes resulting from posture or dynamic factors. The most significant feature of tomosynthesis is its ability to reconstruct a cross sectional image of any desired coronal plane (or sagittal plane for lateral positions) by simply acquiring 36 or 74 images from a single scan parallel to the table, with the patient in any position, and then digitally processing the images. This means it can render minor dislocations, fractures, callus formation, fusing, or synostosis in joints, which are difficult to capture in general radiography images, with minimal effects from metal implant artifacts. This article describes tomosynthesis and how this system has been useful in orthopedic surgery.

2. Tomosynthesis Basics and Characteristics

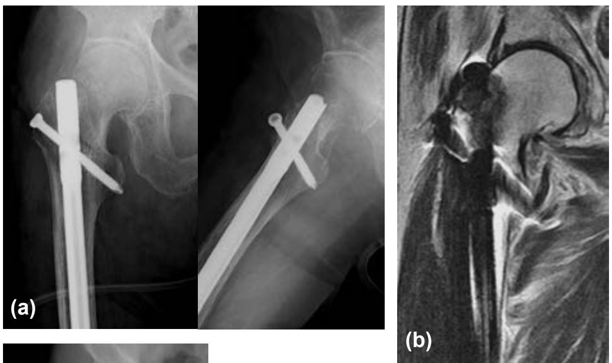
There are two methods used in tomosynthesis to reconstruct images. One is the shift-and-add (SA) method, which shifts the pixels in proportion to the movement between cross section slices. The other is the filtered back projection (FBP) method, which is based on CT reconstruction methods and includes a process to reduce artifacts by adjusting the reconstruction function. The SONIALVISION safire series also features a distortion and halation-free direct-conversion FPD with a 17-inch effective height and width and a wide dynamic range. Consequently, fluoroscopy images can be rendered in high definition. The major characteristics of tomosynthesis using the SONIALVISION safire series are as follows. (1) The FBP method results in cross sections with fewer artifacts in the direction of the imaging chain movement than the SA method, but the effective slice thickness is thicker. (2) Less affected by metal artifacts than CT or MRI. (3) The direct-conversion FPD provides high contrast and high resolution, which results in high resolution cross section images. (4) Radiation exposure dose is about twice the level of conventional orthopedic radiography, but about 1/10 the dose of CT. (5) Tomography is possible with patients in any posture, such as standing, supine, or oblique, or with dynamic loading. Therefore, patients do not need to keep the posture or be restrained for as long, which significantly reduces any discomfort. (6) Images can be examined easily on the monitor. In this way, tomosynthesis provides a unique method of tomography that uses different reconstruction methods than general radiography, CT, or MRI. Therefore, it allows obtaining a wide range of detailed information not previously available. Depending on the disease and pathology, adding tomosynthesis to CT, MRI, or other examination methods can provide more precise diagnoses.

3. Usefulness of Tomosynthesis for Orthopedics

At our hospital, tomosynthesis is mainly used in the orthopedics department and has been helpful for confirming diagnoses or determining treatment protocols. Tomosynthesis by FBP reconstruction is useful for diagnostics because it shows trabeculae clearly, image quality can be adjusted or images reconstructed depending on diagnostic purposes using a workstation. In addition, exposure dose that is lower than CT improves safety for patients and medical personnel. In orthopedics, supplementing fluoroscopy of the spine with functional radiography using tomosynthesis, especially for spinal disease, can help identify dynamic factors contributing to pathology. It is also very useful when artifacts from an implant make it difficult to determine the presence of bone fractures or synostosis. The following are clinical examples where tomosynthesis was especially useful in orthopedics.

Case 1

An open reduction fixation technique was used to install an intramedullary rod in an 84 year old female with a trochanteric fracture of the right hip. After surgery, she was able to walk and was discharged, but fell again at home and was brought back by ambulance. She complained of pain in the treated hip, so a conventional X-ray was taken **(Fig. 1 (a))**, but no bone fractures were evident. Therefore, since we could not determine if it was refractured, we obtained an MRI image **(Fig. 1 (b))**. Nevertheless, due the metal artifact, we still could not determine whether or not there was a fracture, so we used tomosynthesis, which clearly showed a fracture and resulted in diagnosing a refracture **(Fig. 1 (c))**.

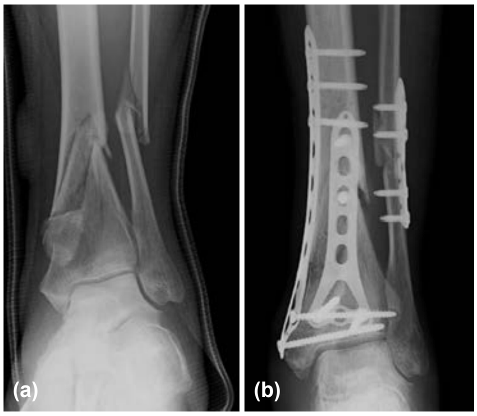


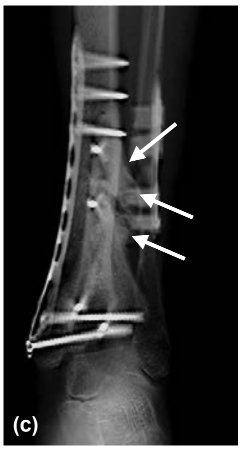
(a) | (b)
(c)

Fig. 1 (a) Refracture of the trochanter is not clear
(b) MRI: Fracture cannot be determined due to artifacts
(c) Tomosynthesis clearly shows refracture line

Case 2

This patient was a 67 year old female with a comminuted fracture of the left ankle **(Fig. 2 (a))**. A plate and screws were installed using an open reduction fixation technique. After the procedure, we observed the progress for three months with no loading, planning to start loading after confirming callus formation. However, plain radiography image after three months revealed a complicated break with multiple fractures and the presence of the implant made it difficult to determine if bone callus was forming **(Fig. 2 (b))**. Therefore, tomosynthesis was used. As a result, callus formation was confirmed about 38 mm from the pretibial surface, so loading was started **(Fig. 2 (c))**.





(a) | (b)
(c)

Fig. 2 (a) Comminuted fracture of the left ankle
(b) Callus formation is not clear in a plain radiography image three months after surgery
(c) Tomosynthesis revealed callus formation 38 mm from pretibial surface

Case 3

This case is an 80 year old female with L4 degenerative spondylolisthesis. A titanium pedicle screw and rod and a PEEK cage was used for a

TLIF procedure between two vertebrae **(Fig. 3 (a))**. Three months after surgery, a CT scan was performed to confirm the synostosis status, but determination was not possible due to artifacts from the PEEK cage **(Fig. 3 (b))**. With tomosynthesis, there were no artifact effects, so the synostosis status could be determined **(Fig. 3 (c))**.

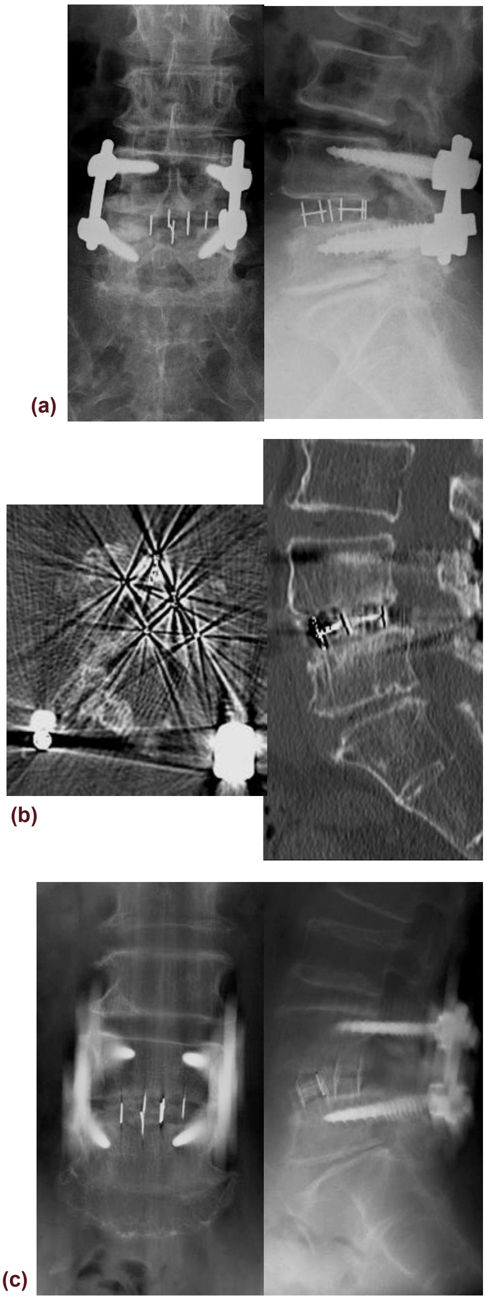


Fig. 3 (a) TLIF performed using PEEK cage
(b) Due to artifacts, synostosis status could not be determined using CT
(c) Tomosynthesis was unaffected by artifacts and allowed determination of synostosis at any slice

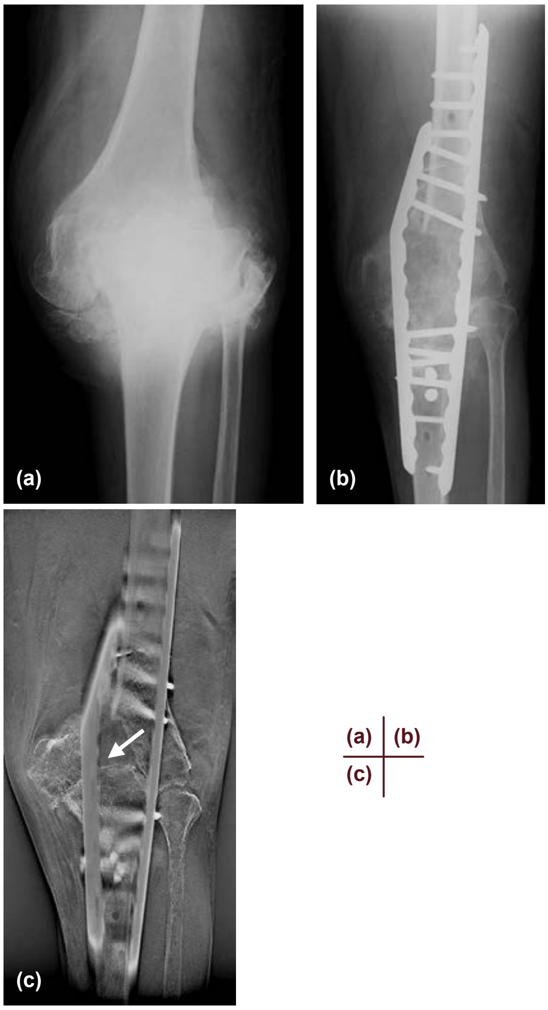
Case 4

For this 22 year old male with atlantoaxial subluxation, occipital cervical fixation was performed with instrumentation and a bone graft from the patient. Three months after surgery, posterior synostosis was confirmed using tomosynthesis images **(Fig. 4)**, so external fixation was terminated.

Fig. 4 Synostosis determined by tomosynthesis three months after occipital cervical fixation

Case 5

This is a 65 year old male with Charcot's joint in the left knee **(Fig. 5 (a))**. His non-painful walking disability caused by knee instability was treated by fixation of the joint. A plain radiography image taken three months after surgery **(Fig. 5 (b))** seemed to show synostosis, but confirmation by tomosynthesis showed air voids remaining in the posterior tibial malleolar and still no synostosis **(Fig. 5 (c))**, so we decided to start loading.



(a) | (b)
(c)

Fig. 5 (a) Charcot's joint in the left knee
(b) A plain radiography image three months after surgery appeared to show synostosis
(c) Tomosynthesis showed voids in posterior tibial malleolar which precluded synostosis determination

4. Summary

Tomosynthesis enables clearly observing bone fractures, callus formation, fusing, synostosis status, and bone and joint structures via cross sectional images, which are difficult to render using general radiography. Undershoot artifacts can appear near metal implants in the body, but tomosynthesis is much less vulnerable to effects from artifacts than CT or MRI and can provide high definition images. In addition, tomosynthesis permits acquiring images with patients in any posture, can be used in combination with functional imaging, and allows acquiring images with the affected area secured by corsets or casts, with no burden on the patient, which makes it an especially useful examination method for orthopedic surgery. On the other hand, obtaining stable image quality requires readjusting X-ray and reconstruction parameters for each patient. In addition, the large amount of data it generates has caused problems with having to wait for images to download to the electronic medical record when examining an outpatient. In terms of image quality, default settings for each patient are not necessarily optimal. Obtaining good images requires changing individual tomography parameters using a workstation, then reconstructing images again. In the future, I hope Shimadzu considers providing image quality at least as good as CR systems and increase the speed of transferring images to the image server in the hospital.

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Clinical Experiences with Tomosynthesis in Orthopaedic Surgery at the Dokkyo Medical University Koshigaya Hospital

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Kazunori Ohashi

Introduction

We used a conventional tomography system at this hospital until June 2007. As most requests for radiography were for patients with bone fractures due to trauma, many of the cases were difficult to observe by plain radiography due to obstructive shadows from the external fixation device or metal implants. We introduced tomosynthesis when the conventional tomography system failed in October 2007. This report presents our clinical experiences with tomosynthesis for orthopedics at this hospital. It introduces the differences in tomosynthesis image quality due to different image reconstruction filters and shows comparisons with CT images.

Clinical Cases

Plain radiography is used for follow-up observations of bone formation after posterior lumbar fixation or external fixation of limb fractures. However, tomosynthesis provides simpler observations **(Fig. 1)**. It also permits confirmation of bone union after femoral bone grafts.

It can be difficult to check bone union at the fracture site after cast immobilization using plain radiography, due to obstructive shadows from the cast. In such cases, too, tomosynthesis eliminates the obstructive shadows and facilitates observations **(Fig. 2)**.

Tomosynthesis imaging during myelography for spinal canal stenosis allows easy observations of the cauda equine at the site of stenosis **(Fig. 3)**.

Differences in Reconstruction Filters

Metal implants are inserted to treat fracture cases. Normal tomosynthesis results in undershooting artifacts during reconstruction that can hinder observations of the site. Metal artifact reduction reconstruction (metal reconstruction) applies direct-current (DC) components to reconstruction filters to reduce the artifacts. We compared images using metal reconstruction with images reconstructed by conventional filtered back projection (FBP) and shift-and-add reconstruction **(Fig. 4)**. Metal reconstruction could reduce undershooting artifacts to provide easier-to-view images.

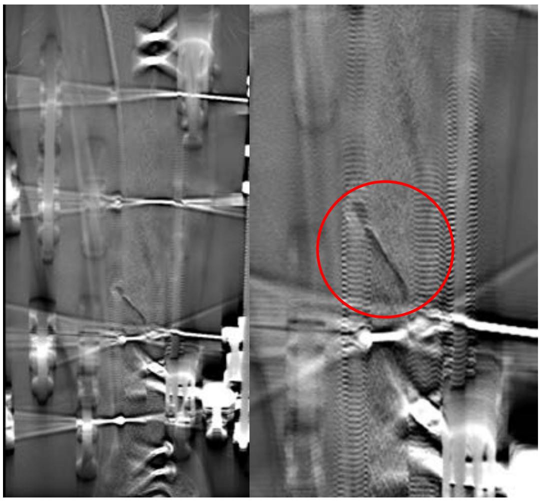

Fig. 1 After Tibial External Fixation (Right: magnified image)

Fig. 2 Cast Immobilization
(a) Plain Radiograph, **(b)** Tomosynthesis Image

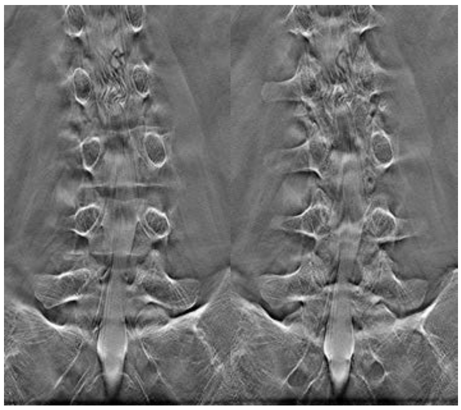

Fig. 3 Myelography (Tomosynthesis Image)

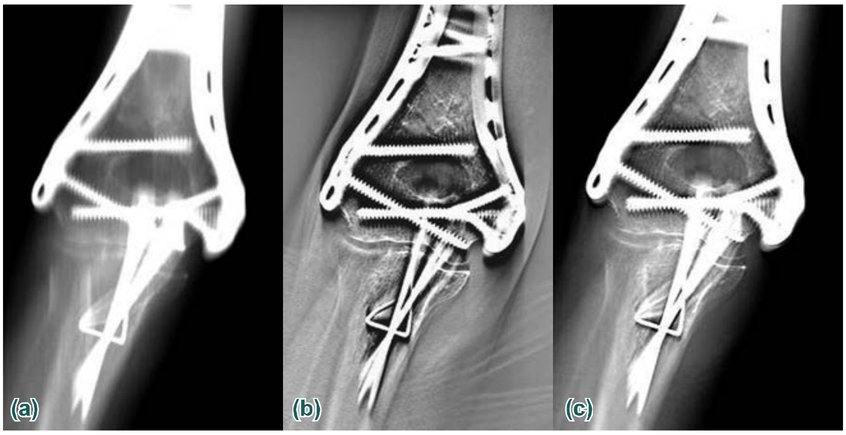

Fig. 4 Reconstructed Images by **(a)** Add-and-Shift, **(b)** Filtered Back Projection (FBP), **(c)** Metal Artifact Reduction

Comparison of CT and Tomosynthesis Images

In cases with metal implants inserted, the direction where metal artifacts occur is different in CT and tomosynthesis images due to the direction of projected data acquisition. Tomosynthesis is thought to be more suitable for follow-up observations after artificial femoral head replacement, due to the different direction in which the artifacts appear at the observation site **(Fig. 5)**. For fine fractures, tomosynthesis images are easier to observe than CT images due to the difference in resolution. Also, thanks to its resolution, the tomosynthesis image is superior for evaluation between a bone spur and a bone fragment from a fracture **(Fig. 6)**. For the reasons above, it is important to use CT scanning or tomosynthesis in examination, depending on the state of the fracture site, by understanding the features of CT scans and tomosynthesis in order to make effective diagnosis.

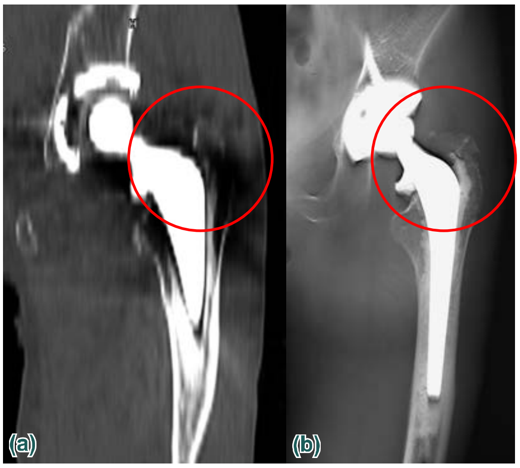

Fig. 5 Femoral Prosthesis
(a) CT Image (MPR), **(b)** Tomosynthesis Image

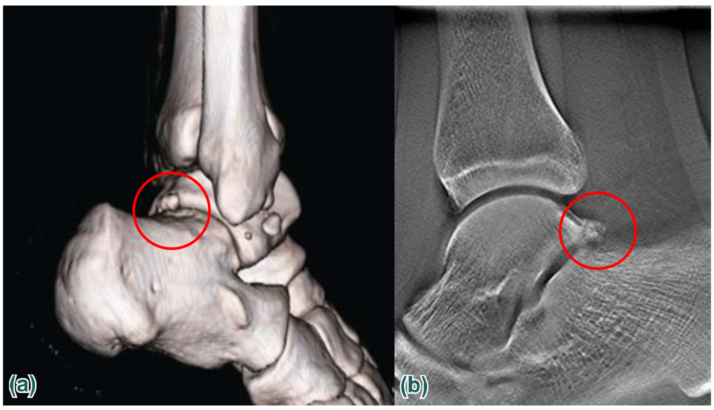

Fig. 6 Ankle
(a) 3-D CT Image, **(b)** Tomosynthesis Image

Summary

This hospital uses tomosynthesis in the field of orthopaedics for observations of bone formation after posterior lumbar fixation and for follow-up observations of external fixation in trauma patients. For cast radiography, the area imaged by plain radiography is immobilized by a cast, such that the range of motion is restricted and adequate patient positioning is not possible. Therefore, this radiography is difficult and the images can be adversely affected by the cast. Tomosynthesis can resolve such problems and the use of different reconstruction filters can reduce the metal artifacts. Tomosynthesis can be used when tomographic images are required in the standing posture, when the direction of the artifacts overlaps the observation site in the CT image, or in cases where plain radiography is inadequate for diagnosis but tomosynthesis can offer satisfactory diagnosis without performing a CT scan. There is little awareness of tomosynthesis by orthopaedic surgeons at this hospital. They do not know that tomosynthesis imaging is adequate for the diagnosis of some diseases, without resorting to CT scans.

To remedy this situation, it is an urgent duty of the X-ray technologists to impart knowledge about tomosynthesis to orthopaedic surgeons and other doctors.

< News Flash >

At the 42nd Annual Meeting of the Japanese Society for Spine Surgery and Related Research (25 to 27 April 2013), Dr. Shuichiro Ohno of the Spine Center, Seirei Hamamatsu General Hospital, made an academic presentation entitled "How Tomosynthesis Changes the Evaluation of PLIF Bone Union." The contents of his presentation are introduced below.

How Tomosynthesis Changes the Evaluation of PLIF Bone Union

Shuichiro Ohno, M.D., Ph.D.

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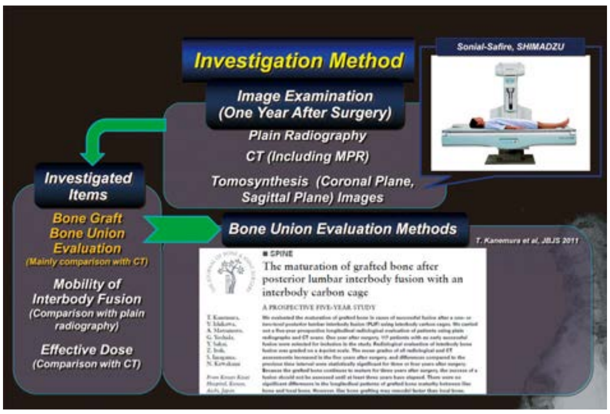
Department of Radiology, Seirei Hamamatsu General Hospital[2]
Spine Center, Konan Kosei Hospital[3]
Shuichiro Ohno[1], Junji Nagano[1], Kanji Sasaki[1], Takafumi Hiroshima[2], Yasuhiro Sakai[2], Yasuyuki Sugiura[2], Tokumi Kanemura[3]

1. Purpose

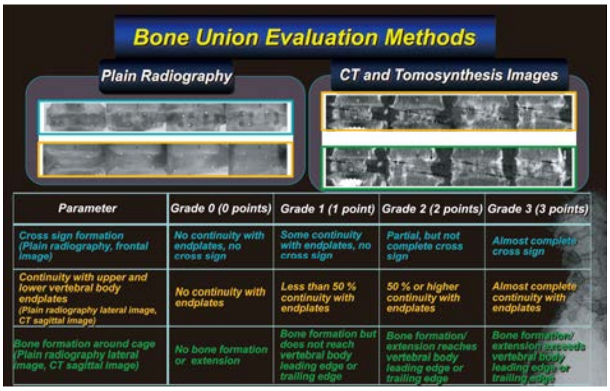
Tomosynthesis is a new radiography technique that takes tomographic images with only one-tenth the exposure dose of CT. It is said to permit rapid radiographic imaging of patients in various postures and dramatically cut metal artifacts. We performed bone union evaluation after posterior lumbar interbody fusion (PLIF) using tomosynthesis and investigated the utility of this technique by comparing it to existing evaluation techniques using radiography and CT.

2. Materials and Methods

Targets were 16 cases of lumbar spinal canal stenosis surgery accompanying lumbar spine instability that permitted diagnostic imaging after one year. The PLIF procedures were performed between April and October 2011. Of these cases, nine were female and seven were male. The average age at surgery was 62.5 years. A total of 18 interbody fusions were performed (one interbody fusion in 14 cases and two interbody fusions in two cases).
The investigation involved radiography, CT, and tomosynthesis one year after surgery. The items evaluated were bone union of the grafted bone, mobility of the interbody fusion, and effective X-ray dose. The grade points method reported by Kanemura et al.[1)] was used to evaluate bone union.



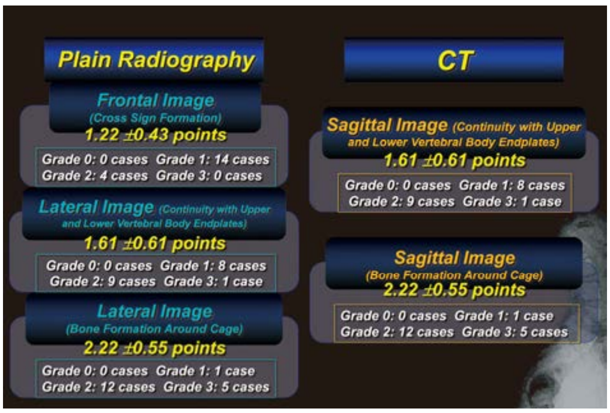
This method of bone union evaluation involves three evaluation parameters, which are each classified from grade 0 to grade 3 and a point score applied. SPSS Ver. 19 was used for statistical studies. The Student-T test and the Wilcoxon signed rank test achieved a significant difference of $p < 0.05$.



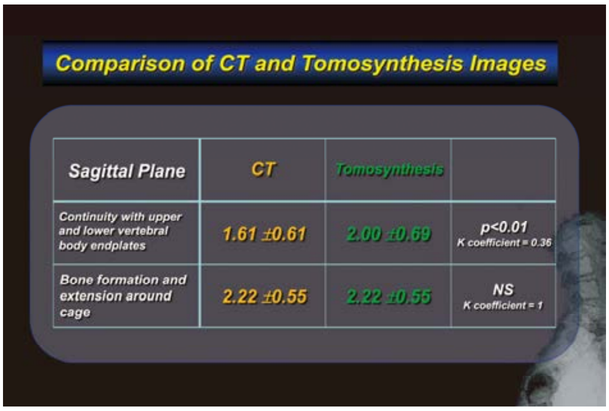
Parameter	Grade 0 (0 points)	Grade 1 (1 point)	Grade 2 (2 points)	Grade 3 (3 points)
Cross sign formation (Plain radiography, frontal image)	No continuity with endplates, no cross sign	Some continuity with endplates, no cross sign	Partial, but not complete cross sign	Almost complete cross sign
Continuity with upper and lower vertebral body endplates (Plain radiography lateral image, CT sagittal image)	No continuity with endplates	Less than 50 % continuity with endplates	50 % or higher continuity with endplates	Almost complete continuity with endplates
Bone formation around cage (Plain radiography lateral image, CT sagittal image)	No bone formation or extension	Bone formation but does not reach vertebral body leading edge or trailing edge	Bone formation/ extension reaches vertebral body leading edge or trailing edge	Bone formation/ extension exceeds vertebral body leading edge or trailing edge

3. Results

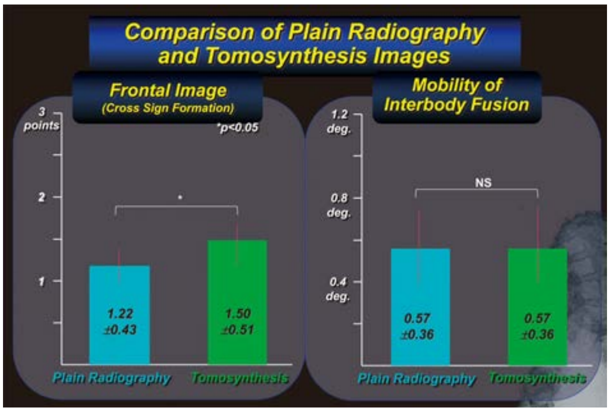
Results of conventional bone union evaluation using radiography were an average 1.22 points for cross sign formation in the frontal images, average 1.61 points for continuity with the upper and lower vertebral body endplates in lateral images, and average 2.22 points for bone formation around the cage. In the CT sagittal plane images, the continuity with the upper and lower vertebral body endplates was an average 1.61 points and bone formation around the cage was an average 2.22 points.



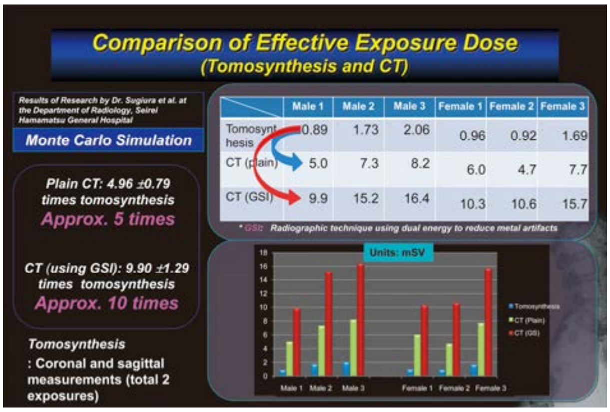
Comparison of CT and tomosynthesis revealed an average 1.61 points for the continuity with the upper and lower vertebral body endplates by CT and an average 2 points by tomosynthesis. A statistically significant difference is confirmed between the two. The kappa coefficient of 0.36 indicates a poor match. However, an average 2.22 points was achieved for bone formation and extension around the cage for both groups. No statistically significant difference was confirmed between the two and the kappa coefficient was 1.



Comparison of radiography and tomosynthesis revealed an average 1.22 points by radiography and average 1.5 points by tomosynthesis for the cross sign formation parameter in the frontal images. A statistically significant difference is confirmed between the two. However, an average 0.57° was achieved for mobility of the interbody fusion for both groups, and no statistically significant difference was confirmed.

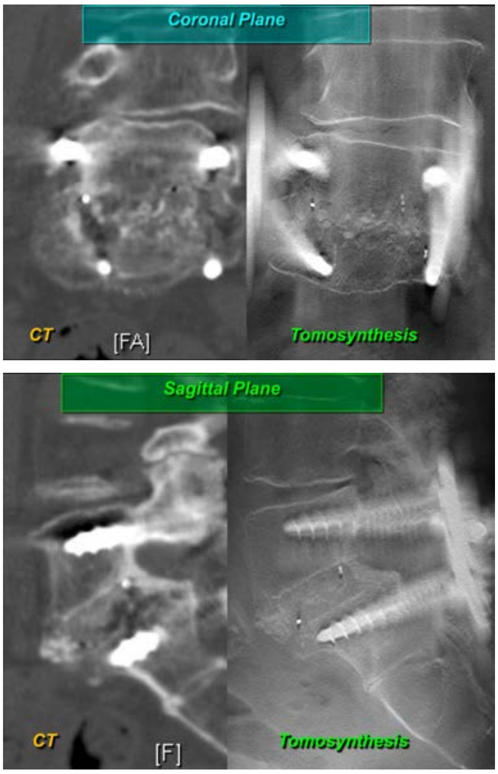


Research by Sugiura et al. at the Department of Radiology at this hospital used Monte Carlo simulation to compare the effective dose between tomosynthesis and CT. Results indicate that plain CT requires approximately five times the X-ray dose of tomosynthesis. CT under conditions that reduce metal artifacts results in ten times the exposure dose.

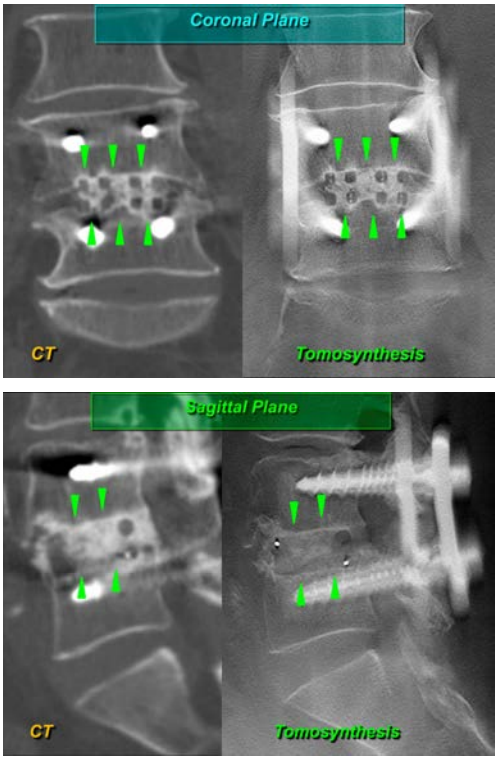


4. Typical Cases

Case 1 is a 78-year-old female with PLIF of L5/S1. Case 2 is a 78-year-old female with PLIF of L4/L5. It is apparent that tomosynthesis produces less artifacts of the screws and metal markers in the cage than CT. It also achieves superior image quality, clearly revealing the boundaries between the vertebral body endplate, cage, and grafted bone. The continuity with the vertebral body endplates and properties within the grafted bone can be clearly observed.



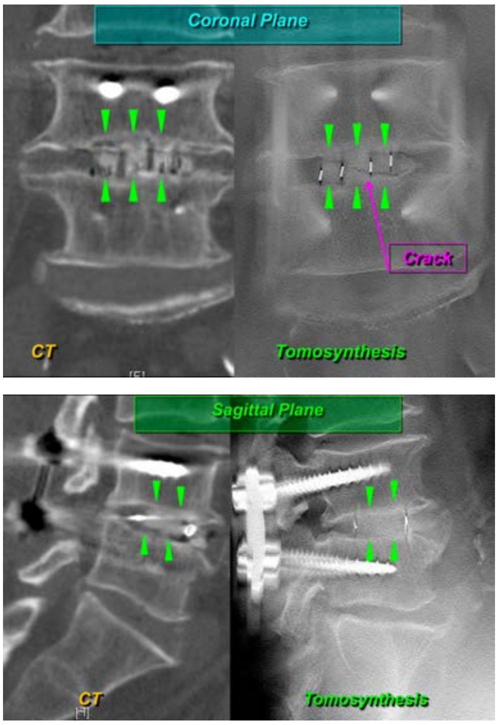
Case 1



Case 2

Case 3 is an 83-year-old male with PLIF of L4/L5. In this case, too, tomosynthesis produces less artifacts of the screws and metal markers in the cage than CT.

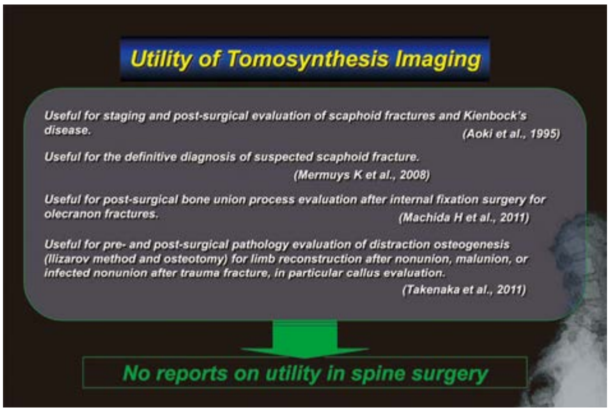
It also achieves superior image quality, such that the continuity of the grafted bone and vertebral body endplates can be clearly observed. Even fine cracks are visible in the grafted bone within or between cages.



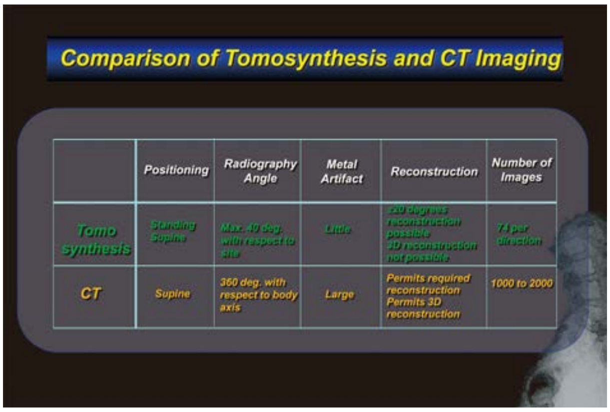
Case 3

5. Discussions

There are very few reports of the utility of tomosynthesis in the field of orthopedics. However, Aoki et al.[2] have reported on its utility for scaphoid fractures and nonunions, as well as staging and post-surgical evaluations of Kienbock's disease. Mermuys et al.[3] have reported on the utility of tomosynthesis for the definitive diagnosis of suspected scaphoid fractures. Machida et al.[4] have reported its utility for bone union evaluation after olecranon fracture surgery. Takenaka et al.[5] have also reported the effectiveness of tomosynthesis for pathology evaluations and callus evaluations before and after distraction osteogenesis for the treatment of limb nonunion and malunion. However, we were unable to find any reports on its utility in spine surgery.



In comparison with CT, tomosynthesis generally offers radiography in both the upright and decubitus positions, fewer metal artifacts, and while it does not permit 3D reconstructions, it permits oblique image reconstruction up to ±20°.



The results of this research into the utility of tomosynthesis for the evaluation of PLIF bone union indicate that it achieves significantly fewer metal artifacts due to pedicle screws and metal markers in cages than CT. Its superior spatial resolution in tomographic plane, better image contrast, and higher image quality offer better evaluation of bone union of vertebral body endplates to bone grafts inside and outside the cages and provide clearer observations of the bone quality inside the grafted bone than with CT. Using a Monte Carlo simulation to compare the effective dose between tomosynthesis and CT indicates that tomosynthesis can cut the dose by 90 %. This indicates that tomosynthesis offers highly safe radiographic image examinations. In the future, tomosynthesis may replace CT as an effective method of radiographic image examination of bone union.

6. Limitations in This Research

The following limitations applied to this research.

1. Few cases and interbody fusions.
2. Evaluations were performed only one year after surgery. In the future, it will be necessary to evaluate long-term data, including periodical evaluations.
3. There is no established evaluation standard for maturation of bone grafts inter and intra cages.
4. Comparative investigations are required of functional radiographic images by CT and tomosynthesis.
5. Comparative investigations are required into measured exposure dose values for CT and tomosynthesis under the radiography conditions actually used.

7. Conclusions

Tomosynthesis achieves significantly and fewer metal artifacts due to pedicle screws and metal markers in cages than CT. It makes image evaluation easier.
In comparison with CT, tomosynthesis requires short imaging times of just 2.5 to 5 seconds and achieves approximately one-tenth the exposure dose. It offers highly safe radiographic image examinations.
In the future, tomosynthesis may replace CT as an effective method of radiographic image examination of bone union.
As evaluations were performed only one year after surgery and involved few cases, it will be necessary to evaluate long-term data in the future, including periodical evaluations.

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Dr. Shuichiro Ohno plans to establish the Ohno Orthopedics & Spine Clinic in Hamamatsu City, Shizuoka, Japan on November 13, 2013. Dr. Ohno will use the SONIALVISION safire system in the new clinic and perform further research into the utility of tomosynthesis in orthopedics.

http://www.ohnoseikei.com/

Use of Tomosynthesis at the Aizawa Hospital

Mr. Masahiro Iwama

Diagnostic Imaging Center, Aizawa Hospital
Masahiro Iwama, Kei Takehara, Kouichi Anraku

1. Introduction

The Aizawa Hospital is located in Matsumoto City, in the Chushin area of Nagano Prefecture, and was certified as a regional medical care support hospital in August 2001. As such, we serve a central role in coordinating medical services in the region. Furthermore, in April 2003, we were certified as a designated clinical training hospital. In April 2005, we were designated as a new emergency care center for the Chushin district. Therefore, as a central hospital responsible for acute medical care in the Chushin district, we accept all emergency patients 24 hours a day, 365 days a year, and aim to help create a region where citizens can live without worrying about emergency medical care. In 2008, we celebrated our 100 year anniversary and that same year was designated as the regional coordinating hospital for cancer treatment in February and as a social medicine provider highly beneficial to society and concerned with the common good in December. The 502-bed Aizawa Hospital contributes to society by providing high quality medical and related services **(Fig. 1)**.

Fig. 1 Aizawa Hospital

. Use of Tomosynthesis at the Aizawa Hospital

We are currently using a SONIALVISION safire series R/F table system **(Fig. 2)** that was introduced in March 2011. The fluoroscopy room is used for a variety of examinations, such as urinary, surgical, orthopedic, and internal medicine examinations, and endoscopic examinations in the afternoon. The R/F table system recently acquired from Shimadzu is capable of tomosynthesis, which we planned to utilize effectively as a new examination tool and improve the operating efficiency of the R/F table system. However, first we needed to have orthopedic physicians request tomosynthesis, so when the system was being introduced, we held a workshop within the hospital to study the advantages of tomosynthesis based on clinical examples of imaging. The technologists actively discussed their views with the physicians about the potential of tomosynthesis and the areas where tomosynthesis is likely to have an advantage over plain radiography. In turn, the physicians also offered their views on areas where they thought tomosynthesis might be useful. As a result, the number of tomosynthesis cases gradually increased. To confirm and maintain the precision level of examinations, we collect physicians' diagnostic comments from electronic medical records for examinations performed. This information is then shared among relevant personnel. In addition, internal email is used as a method of communicating with physicians to exchange views.

Fig. 2 Currently Used System

Fig. 3 shows the number of cases using tomosynthesis during a one-year period from April 2011 to March 2012, broken down by month. All 114 cases were for orthopedic examinations. The number of cases varied depending on the month, suggesting that the use of tomosynthesis is not fully established. Next we need to analyze the number of cases for each physician to obtain the views of physicians with low usage rates and resolve any issues they may have. In general, examinations are ordered on a reservation basis, but unscheduled same-day examination requests are also accommodated.

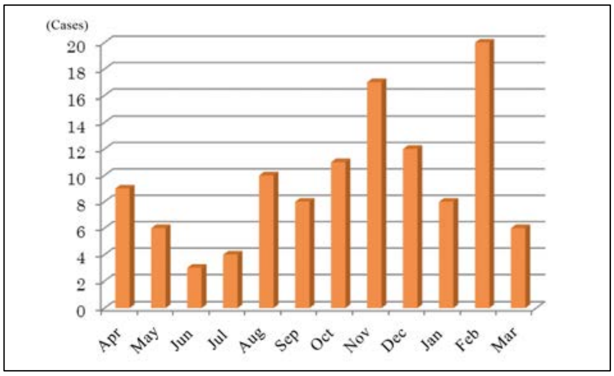


Fig. 3 Number of Tomosynthesis Cases by Month (FY 2011)

Fig. 4 shows a breakdown by target imaging area, with 16 elbow cases being the most common and the spine the next most common. We surveyed the orthopedic physicians to determine why there were so many cases of using tomosynthesis for the elbow. Responses included that though the elbow joint is small, it has a complicated structure that makes it difficult to evaluate olecranon fractures or synostosis using plain radiography images. Also, tomosynthesis is especially effective in evaluating trabeculae and synostosis near K-wires and metal objects used to secure implants and is also useful for evaluating synostosis while bones are still secured by a cast.

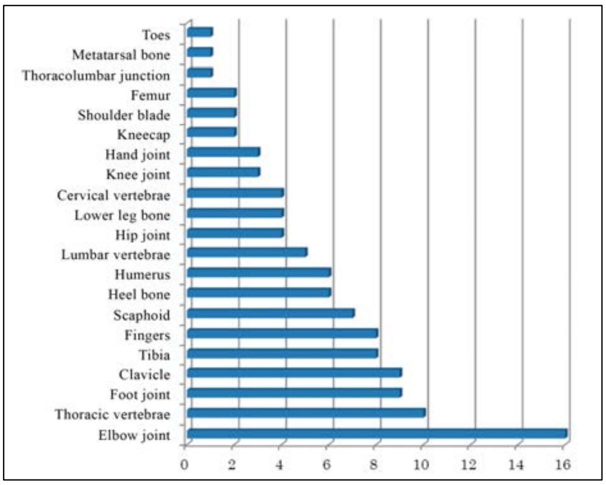


Fig. 4 Number of Tomosynthesis Cases by Target Area

3. Usefulness of Tomosynthesis

Because tomosynthesis is especially effective in reducing metal artifacts and is able to render even trabeculae, in about 90 % of the cases, tomosynthesis is used for evaluating synostosis **(Fig. 5)**. It is next most commonly used to determine the presence of bone fracture lines.

Fig. 6 shows the number of cases with an implant or other metal object in the target area. If an implant is present when trying to evaluate synostosis, the metal artifact will affect CT scans and other diagnostic imaging methods, making it difficult to evaluate the synostosis, but tomosynthesis is able to minimize the effects of metal artifacts. Therefore, it is preferred for such cases. Also, in cases with implants or other metal objects, tomosynthesis uses filtering to provide two types of images, Metal4 and Thickness++ images. This is because Metal4 allows reducing artifacts around metals more than Thickness++, but edge enhancement is weaker than Thickness++. Therefore, the characteristics of both images are considered.
Physician diagnoses were collected from electronic medical records and sorted into positive, false-positive, and no-record categories **(Fig. 7)**. Diagnoses were recorded in 80 % of the cases. This indicates that tomosynthesis results were reflected in physician diagnoses.
It has been one year since we started operating the tomosynthesis system, and cases where tomosynthesis is used for follow-up examinations have started to increase **(Fig. 8)**. The reasons for the increase include that though it is used for a variety of target areas, it is more useful for diagnosing synostosis than are plain radiographs, it uses lower exposure levels and is more effective for diagnoses that involve implant artifacts than CT, and its insurance point cost is lower, which enables short-term follow-ups.

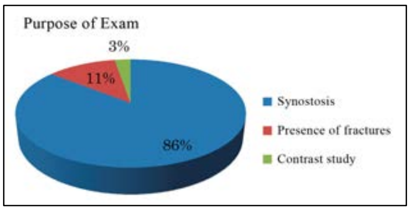


Fig. 5

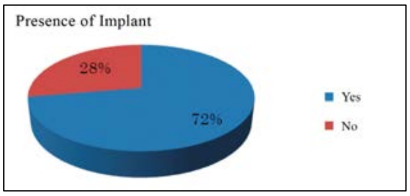


Fig. 6

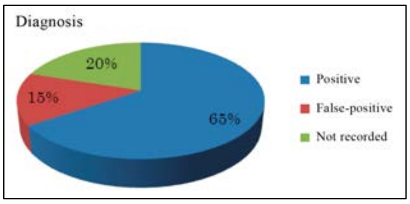


Fig. 7

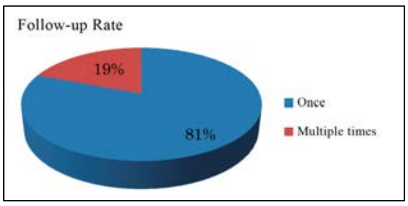


Fig. 8

4. Case Studies

4.1. Case 1 – 57-year-old male

Main complaint: Back pain

Case history: Fell down stairs. Upon hearing a sound, the patient was found fallen at the bottom of stairs with 12 steps. Patient was secured with a backboard and neck collar, and transported to our hospital by ambulance.

Imaging: CT scans of head, face, and neck, contrast-enhanced CT of chest/abdomen, and MRI of thoracic vertebrae

Hematoma in forehead, fracture of right 7th rib, burst fracture of 6th thoracic vertebra, and suspected compression fracture of 5th and 9th thoracic vertebrae **(Fig. 9)**

Treatment strategy: Since dorsal column components were retained from the burst fractured 6th vertebra, a body cast was applied for conservative therapy, followed up with tomosynthesis imaging (6 days later). A spinous process fracture was indicated **(Fig. 10)**.

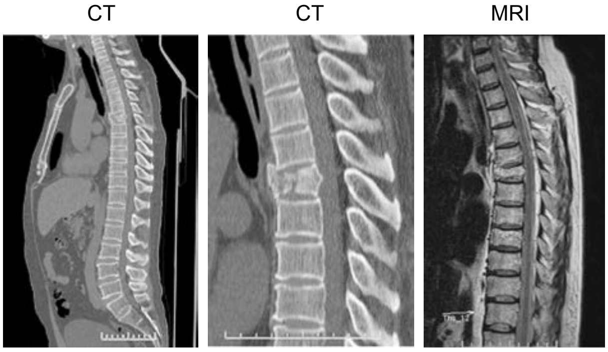


Fig. 9

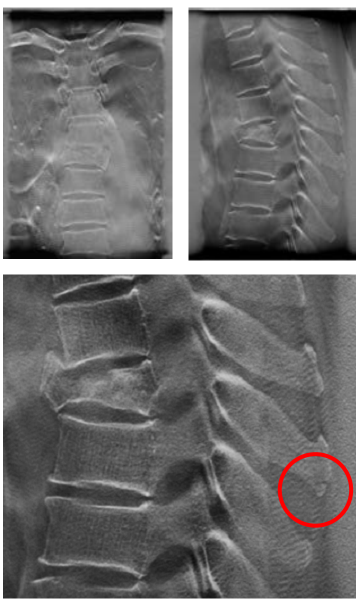


Fig. 10

X-ray parameters: 100 kV, 5 mAs
Tomographic angle: 40 deg.
Exposure time: Slow (5 s)
Resolution: High (15 fps)
Slice pitch: 2 mm
Reconstruction method: FBP
Filter: Thickness++

Compression fracture of the 5th thoracic vertebra was negative.

4.2. Case 2 – 86-year-old female

Main complaint: Right femoral pain

Case history: Hannson pin fixation of right femoral neck fracture in December 2008. In October 2011, patient experienced severe pain in right femur when waking up. Pain increased and walking became difficult, so she went to the ER.

Current symptoms: Tenderness in femoral triangle. Rotation, bending, or extension of hip joint causes pain.

Imaging: Tomosynthesis was added due to suspected right epiphysis fracture line in hip joint plain radiography **(Fig. 11)**.

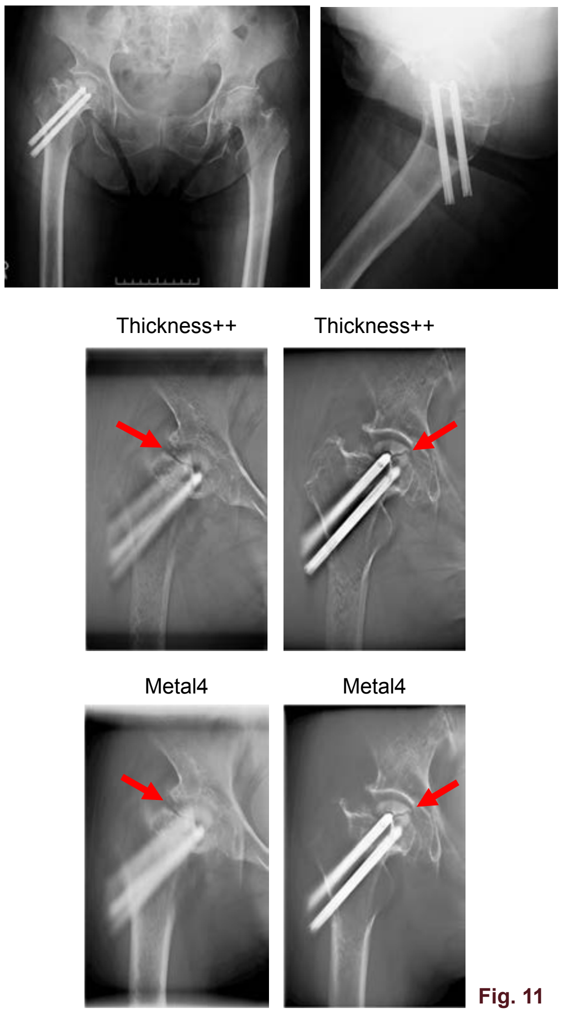


Fig. 11

X-ray parameters: 80 kV, 2.5 mAs
Tomographic angle: 40 deg.
Exposure time: Slow (5 s)
Resolution: High (15 fps)
Slice pitch: 2 mm
Reconstruction method: FBP
Filters: Thickness++, Metal4

4.3. Case 3 – 66-year-old male

Main complaint: Neck pain

Case history: Fell about 2.5 meters from a step ladder at 7:25 a.m. in October 2011 and hit his head and back. After he was unconscious or his consciousness was impaired for about one minute, an ambulance was called. When emergency medical technicians arrived, he was sitting and able to walk.

Past history: Surgery for spinal stenosis

Imaging: CT scan of head and plain radiography, CT, and MRI scans of cervical vertebrae indicated fracture lines in 6th and 7th cervical vertebrae and anterior surface of 1st thoracic vertebra.
Epidural hematoma **(Fig. 12)** was also present. Plain radiography and tomosynthesis in follow-up exam (2 months later) clearly showed grafted bone in tomosynthesis image **(Fig. 13)**.

X-ray parameters: 80 kV, 1.25 mAs
Tomographic angle: 40 deg.
Exposure time: Slow (5 s)
Resolution: High (15 fps)
Slice pitch: 2 mm
Reconstruction method: FBP

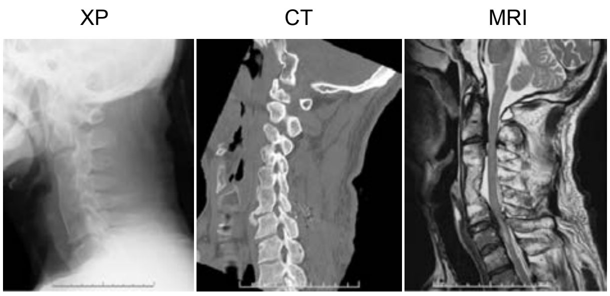


Fig. 12

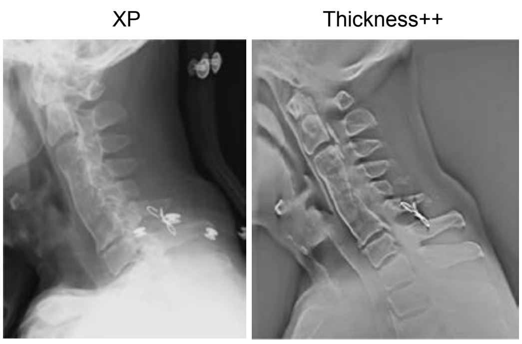


Fig. 13

Filter: Thickness++
Images taken in sitting position. Grafted bone identified in 6th cervical vertebra

4.4. Case 4 – 57-year-old male

Main complaint: Precordial chest and back pain

Case history: Fell forward during motocross bike practice. Pain in left precordial chest and back. Transported by ambulance. He was wearing a helmet.

Imaging: Performed plain radiography of chest and thoracic vertebrae and CT scans of head and thoracic vertebrae, then obtained MRI images of thoracic vertebrae the next day **(Fig. 14)**. Burst fracture of 2nd thoracic vertebra, fractured sternum, and lung contusion

Treatment strategy: Posterior fixation of 7th cervical to 4th thoracic vertebrae and autogenous bone graft performed. Plain radiography **(Fig. 15)** performed 7 days after surgery. While the lateral view, obscured by shoulders, did not allow comparison with the post-surgical image, the front view showed no movement in screws or other changes.

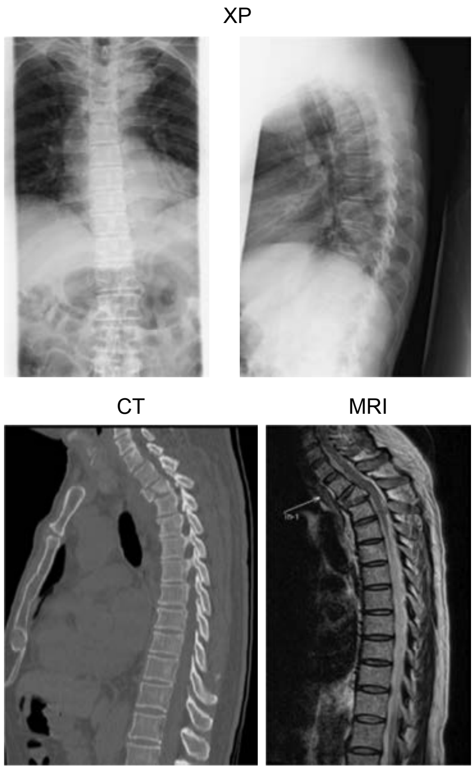


Fig. 14

XP (Day 7)

Fig. 15

CT scan **(Fig. 16)** performed 12 days after surgery. Fracture was mostly reintegrated and protrusions on posterior surface of vertebrae disappeared.

Tomosynthesis **(Fig. 17)** performed 1 month after surgery

X-ray parameters:	100 kV, 5 mAs
Tomographic angle:	40 deg.
Exposure time:	Slow (5 s)
Resolution:	High (15 fps)
Slice pitch:	2 mm
Reconstruction method:	FBP
Filter:	Thickness++

CT (Day 12)

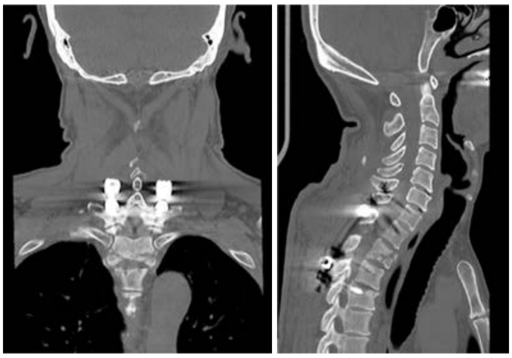


Fig. 16

Tomosynthesis

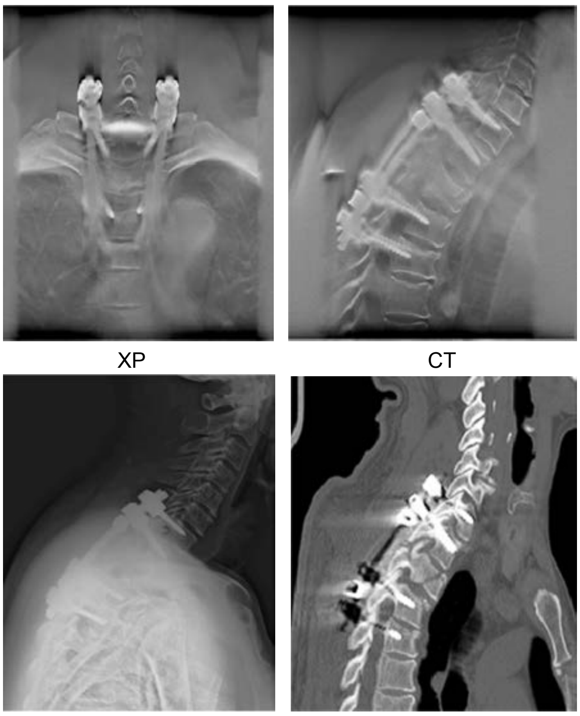


Fig. 17

In this case, the physician thought that tomosynthesis was more useful than plain radiography for determining alignment from examination images **(Fig. 17)**. Tomosynthesis was the most effective in judging screw loosening, followed by CT and plain radiography, in that order. However, CT was more effective than tomosynthesis for diagnosing synostosis.

5. Summary

Tomosynthesis is offered as additional functionality on SONIALVISION safire series R/F table systems. Because fluoroscopy can be used for positioning, images can be obtained in positions optimized for diagnosis. Tomosynthesis requires lower exposure levels and has a wider dynamic range than CT, which makes it superior for minimizing metal artifacts. In the case of scaphoid bones, it also allows diagnosing whether synostosis is progressing from the palmar or dorsal side. According to the orthopedic physicians at our hospital, CT is preferred for diagnosis during initial evaluation of bone contusions (to determine overall status and form of bone fractures and so on), but tomosynthesis is preferred for diagnosis in follow-up examinations due to evaluation of synostosis.

Issues include undershooting from implants affecting the determination of synostosis and difficulty in evaluating fracture lines when they are parallel to the direction of X-ray tube movement during exposure. Improvements are required on these issues by using reconstruction filters or by using positioning techniques that use fluoroscopy to consider the orientation of implants that minimizes effects on fracture lines. Though other facilities use tomosynthesis for many other applications, such as in respiratory, otolaryngologic, and dental applications, at Aizawa Hospital it is currently only used for orthopedic examinations. Therefore, we hope to expand the range of applications by educating the various departments.

Tomosynthesis has progressed to become an essential part of diagnostic imaging. We look forward to further major advancements in the future as well, such as those that use successive approximation methods for reconstruction. After becoming more familiar with the features of our current system, we hope to utilize the system in new application fields.

Experiences with Cochlear Implant examination Using Tomosynthesis

Department of Radiology, Shinshu University Hospital
Manabu Takei

Introduction

Cochlear implants comprise instruments positioned inside and outside the body. The external microphone receives external sounds, which are converted to electrical signals by a speech processor and then transmitted into the body by an antenna. The signals introduced into the body are transferred as electrical signals by the intracochlear electrodes into the auditory nerve to be perceived as sound.
The type and intensity of the sound differ according to the combination of stimulated electrodes. At this hospital, we use cochlear implants with 12 or 24 electrodes.

Utility of Tomosynthesis

CT and MRI are currently the mainstream imaging methods for the head and neck region. However, electrodes and other metal components can cause artifacts that destroy information.
Tomosynthesis, however, achieves high spatial resolution with few metal artifacts and can acquire multiple tomographic images from a single acquisition, making it ideal for detailed examinations of cochlear implants. Positioning under fluoroscopy can be performed prior to radiography to avoid overlapping of electrodes and to enhance reproducibility.

Aim

At this hospital, inner ear tomography by tomosynthesis has become routine for post-operative evaluations after cochlear implant surgery. In addition to providing clinical images, we report on our investigation of patient positioning and the effects of the swing angle and image reconstruction filters to acquire images with maximum utility for diagnosis.

Images Deemed Useful

Section images perpendicular to the modiolus (parallel to the turn of the lamina basilaris cochlea) that show the electrodes inserted into the cochlear in a single sectional image.
Images with minimal artifacts that maintain the contrast between the electrode and cochlear wall are deemed to be useful images.

Method

1) Investigating the Tomography Swing Angle
   A glass dosimeter was attached to the orbital region of a head phantom. The exposure dose was measured at the lens position at swing angles of 8°, 30°, and 40°. Next, a 10 cm acrylic phantom was used with a one-yen coin positioned at a height of 5 cm and the SN ratio was determined using the following equation:
   SNR = Mean Signal/SD BG
2) Investigating Image Reconstruction Filters
   The SN ratios for an SNR measurement phantom containing embedded $CaCO_3$ of different densities (manufactured by Kyoto Kagaku Co., Ltd.) were calculated and compared for image reconstructions using shift-and-add, filtered back projection (FBP), and FBP + CV filters (DC4, 6, 8, 10). Clinical images obtained while changing the reconstruction filters (as above) were evaluated by an ear, nose and throat specialist.

Results

1) The larger the swing angle, the lower the exposure dose at the lens (organ at risk) **(Fig. 1)**.
   This is believed to occur because the distance from the focal point to the lens increases as the swing angle becomes larger.
   When measuring the SN ratio with an acrylic phantom, the pixel values vary little with the swing angle, but the SD tends to decrease as the swing angle increases.
   Therefore, the SN ratio increases as the swing angle increases **(Fig. 2)**. Consequently, the swing angle was set to 40°.
2) The investigations into image reconstruction filters reveal that filtered back projection (FBP) achieved the highest SN ratio, and the SN ratio dropped off as the direct current (DC) component increased **(Fig. 3)**.
   Inputting DC components during clinical image evaluation reduces undershooting but tends to lose the contrast of the electrode and cochlear wall. Consequently, we selected filtered back projection (FBP) as the image reconstruction filter **(Fig. 4)**.

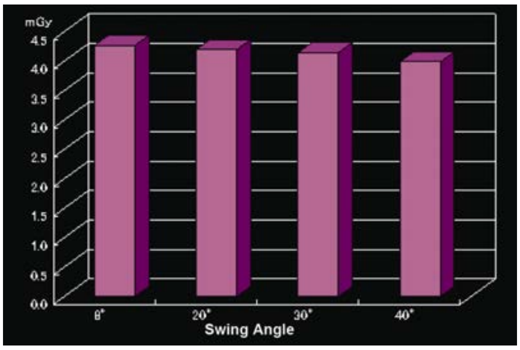


Fig. 1

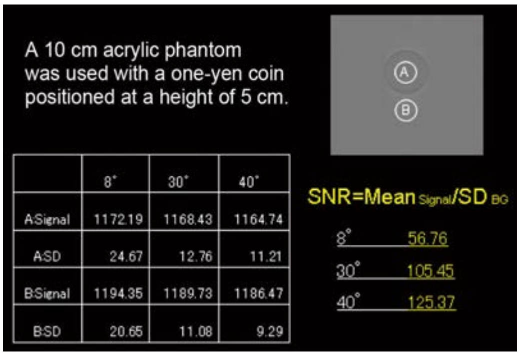


Fig. 2

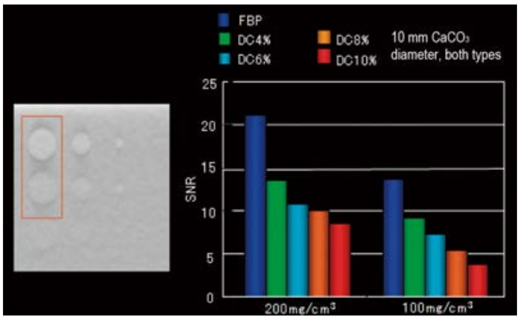


Fig. 3

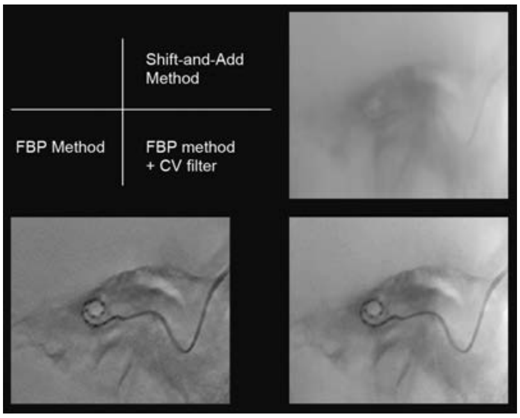


Fig. 4

Radiography Conditions and Clinical Images

The radiography conditions are shown below. The patient positioning is based on the Stenvers method, due to the wider view of the base of the lamina basilaris cochlea. As the examination was performed immediately after surgery, radiography was performed using the reverse Stenvers method in the supine position.

System used: SONIALVISION safire
Positioning: Reverse Stenvers method
80 kV, 1.8 mAs, 7.1 ms
SID: 110 cm 6 inch
Tomography swing angle: 40°
Tomography speed: Fast
Frames: 67 frames
Image reconstruction method: FBP
Image reconstruction pitch: 1 mm

Case 1: 68-year-old male
A cochlear implant was surgically implanted on the right side due to advanced bilateral sensorineural hearing loss. Fig. 5 shows a tomosynthesis image taken on the day after surgery. All 12 electrodes are visible in a single sectional image and the contrast of the cochlear wall is maintained. The position was confirmed at the center of the cochlear nerve and distances could be measured.

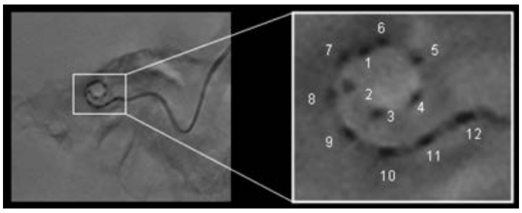


Fig. 5

Case 2: 32-year-old male
A cochlear implant was surgically implanted on the right side due to advanced bilateral sensorineural hearing loss. Fig. 6 shows an image of the 24 electrodes. All 24 electrodes are visible in a single sectional image, but the distances between the electrodes are less distinct than for 12 electrodes. This results from the effects of adjacent electrodes in the tomographic direction due to the short distances between the electrodes.

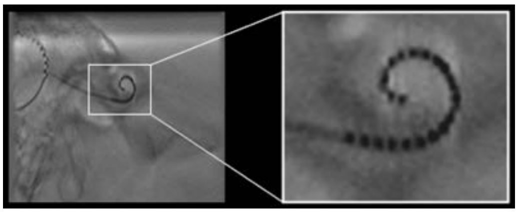


Fig. 6

Discussion

Tomosynthesis suffers less from metal artifacts, achieves higher spatial resolution, and acquires images at a lower exposure dose than computed tomography (CT). For inner ear radiography, viewing all electrodes in a single sectional image using filtered back-projection (FBP) is relatively simple due to the increased slice thickness. However, careful consideration of the cochlear angle and tomographic direction is required to separate each electrode. As the contrast is maintained between the electrodes and cochlear wall, it is possible to measure distances from the modiolus to the electrodes and to cochlear wall. Consequentially, tomosynthesis has utility for the post-operative evaluation of cochlear implants.

< News Flash >

Dr. Teppei Omori of the Department of Gastroenterological Medicine, Tokyo Women's Medical University Hospital, made a presentation on the Shimadzu SONIALVISION safire Digital R/F System at the 85th general meeting of the Japan Gastroenterological Endoscopy Society (10 to 12 May 2013), entitled "Current Status and Future Possibilities of Gastrointestinal Tract Patency Evaluation Using Patency Capsules." The contents of his presentation are introduced below.

Current Status and Future Possibilities of Gastrointestinal Tract Patency Evaluation Using Patency Capsules

Dr. Teppei Omori

Department of Gastroenterological Medicine, Tokyo Women's Medical University Hospital
Teppei Omori, Shinichi Nakamura, Keiko Shiratori

1. Background and Purpose

In Japan, gastrointestinal tract patency evaluations using patency capsules (PC) have been covered by health insurance since July 2012. This has expanded the range of diseases to which capsule endoscopy (CE) is applied. If the PC is not egested from the body, abdominal radiography is used to evaluate gastrointestinal tract patency but in many cases it is difficult to identify the PC position.

We have been investigating more accurate PC position evaluation method through PC experience in our hospital. This paper reports on our experiences using PC and on PC position evaluation by tomosynthesis.

2. About CE and PC

CE has been used as an examination method for clinical applications for about ten years. In Europe and in the United States, CE for the esophagus and large intestine, in addition to the small intestine, have been marketed and widely applied. Application of CE in Japan is entering its sixth year. Currently marketed capsule endoscopies are designed for the small intestine. Two types of device are used: the PillCam® SB Series manufactured by Given Imaging Ltd. and the Olympus endoCapsule®. The major features of capsule endoscopy are its low invasiveness and ability to perform safe examinations of the small intestine.

However, unlike in overseas, health insurance in Japan had covered only capsule endoscopy of the small intestine in cases of gastrointestinal bleeding of unknown cause. Its use in cases of other diseases had not been allowed.

The launch of the PillCam® SB2 plus in July 2012 expanded the range of targeted disorders to actual and suspected small intestine diseases in Japan. This permits application to scrutiny of intestinal lesions in constrictive diseases with the potential for retention, such as definitively diagnosed and suspected Crohn's disease, after the risk of capsule retention—as a complication in capsule endoscopy—is eliminated by evaluating gastrointestinal tract patency using a PillCam® Patency Capsule. (Capsule retention is defined as retention of the capsule endoscopy in the body for two weeks or more, which may require surgical intervention.) See **Fig. 1**.

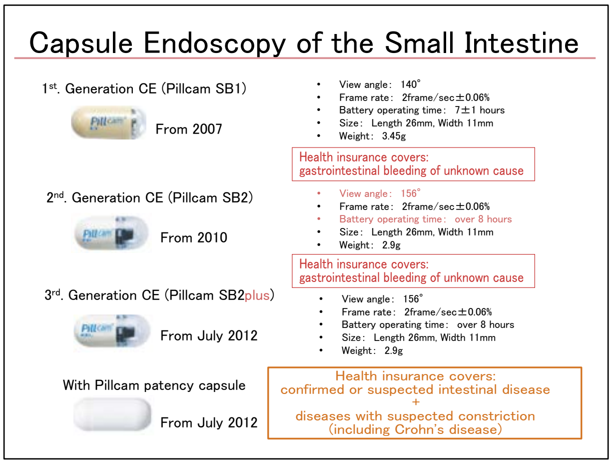


Fig. 1

3. Intestinal Patency Evaluation

The PillCam® Patency Capsule (PC) has the same shape as the PillCam® SB2 plus, with dimensions of 26 × 11 mm. It is encapsulated in lactose containing 10 % barium sulfate **(Fig. 2)**. The PC is ingested orally. If (1) egestion from the body by defecation is confirmed or (2) abdominal radiography confirms it has reached the large intestine, after 30 to 33 hours without change in shape, the risk of retention of the same-sized PillCam® SB2 plus is deemed extremely low, indicating that small intestinal examination by capsule endoscopy is applicable.

Approximately 30 hours after ingestion, intestinal juice start to permeate from both ends of the PC, causing it to be dissolved. After about five days, only a thin coating film will remain. This eliminates the risk of PC retention that requires surgical intervention **(Fig. 3)**.

However, in the actual clinical practice, it is often difficult to locate the PC position by using abdominal radiography.

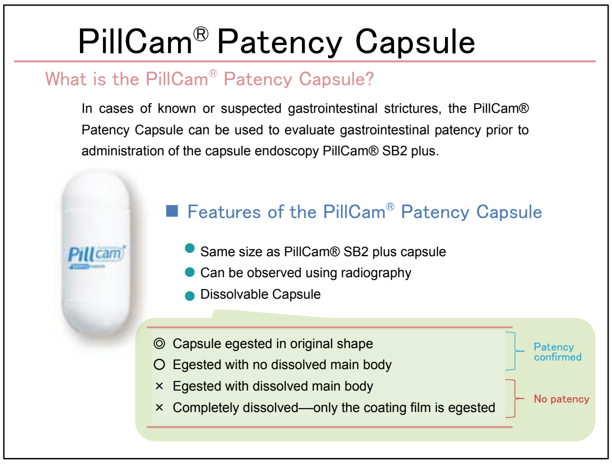
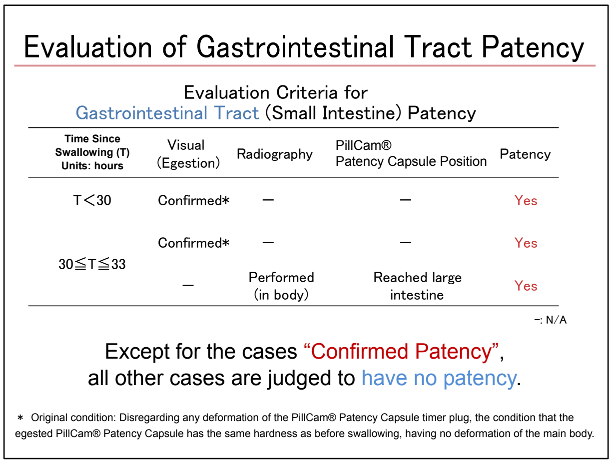


Fig. 2



Evaluation of Gastrointestinal Tract Patency

Evaluation Criteria for Gastrointestinal Tract (Small Intestine) Patency

Time Since Swallowing (T) Units: hours	Visual (Egestion)	Radiography	PillCam® Patency Capsule Position	Patency
T<30	Confirmed*	–	–	Yes
30≦T≦33	Confirmed*	–	–	Yes
	–	Performed (in body)	Reached large intestine	Yes

–: N/A

Except for the cases "Confirmed Patency", all other cases are judged to have no patency.

* Original condition: Disregarding any deformation of the PillCam® Patency Capsule timer plug, the condition that the egested PillCam® Patency Capsule has the same hardness as before swallowing, having no deformation of the main body.

Fig. 3

4. Experiences Using PC at This Hospital

In the period between July 2012 and the end of November 2012 we used PC to evaluate gastrointestinal tract patency prior to CE in 36 cases (33 cases of Crohn's disease, two cases of suspected small intestinal tumor, and one case of intestinal Behçet's desease). The position could be evaluated visually or by abdominal radiography in 63.9 % of cases. Conversely, positional evaluation (whether in the small intestine or large intestine) by abdominal radiography was difficult in 36.1 % of cases **(Fig. 4)**.

Among these clinical cases where evaluation was difficult, in one case which we judged the PC was in large intestine, we experienced CE retention. The actual PC position was the narrowing of the terminal ileum and the CE was retained at this constriction. In this case, stricture dilation was performed by double-balloon enteroscopy to recover the CE **(Fig. 5 and Fig. 6)**.

In cases where the positional evaluation was difficult, the PC tended to be located in the pelvic cavity. At this hospital, we used additional abdominal radiography (lateral or lateral recumbent) and abdominal ultrasonography in such cases but this often did not lead to a definitive judgment of the positions.

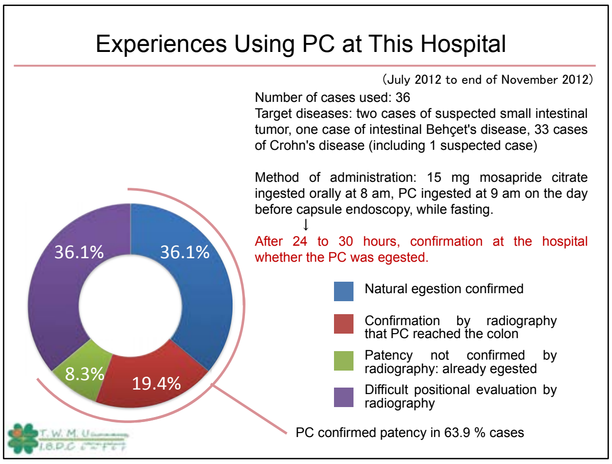


Fig. 4

Fig. 5

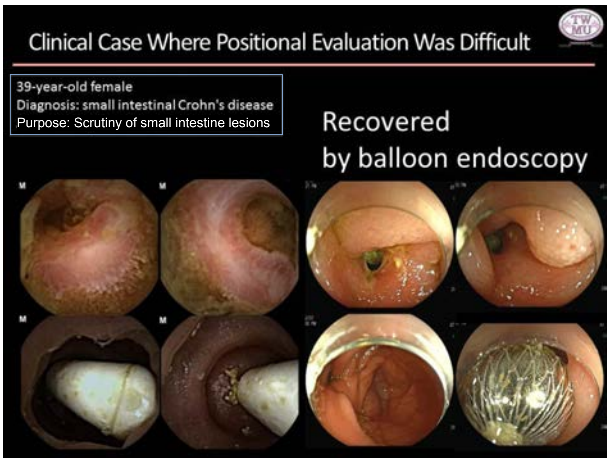


Fig. 6

5. Issues of Patency Evaluation by Abdominal Radiography

We believe that the structure of the abdominal cavity is related to the difficulties in identifying the PC position by abdominal radiography. The small and large intestines are compressed within the restricted space inside the abdominal cavity and the morphological information on soft tissues overlaps in abdominal radiographs, making identification of the PC position difficult **(Fig. 7 and Fig. 8)**. Using CT makes positional identification easier but this procedure should not be taken without paying attention to X-ray exposure dose and medical expenditure.

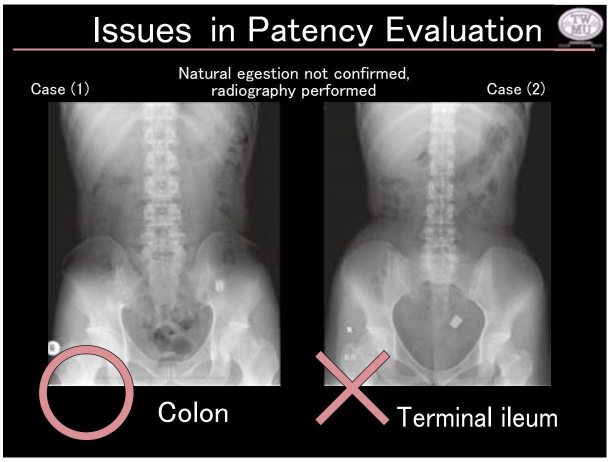


Fig.7

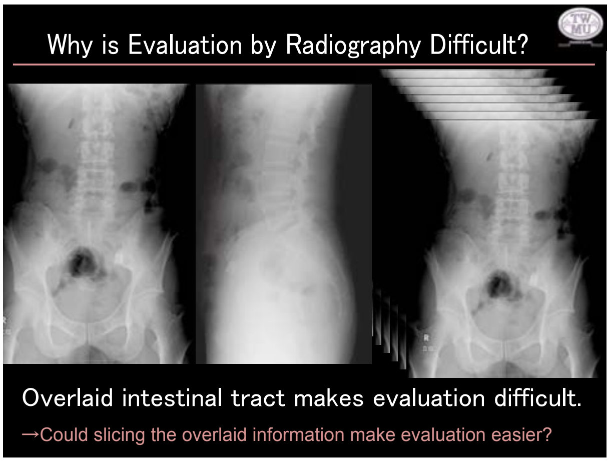


Fig.8

6. Patency Evaluation by Tomosynthesis

Wondering if slicing up the overlaid morphological information would permit positional evaluation of PCs, we used tomosynthesis on the abdominal soft tissue. One of the cases is introduced here.
In the abdominal radiograph, the PC is located on the left side of the pelvis, making positional evaluation difficult. However, the tomosynthesis images which were taken at almost the same time as radiography showed the path of the colon clearly and the PC was identified in the sigmoid colon **(Fig. 9)**. Other tomosynthesis images show the paths of the ascending, transverse, and descending colons **(Fig. 10)**, suggesting that the PC position should be identified at other locations in the large intestine.

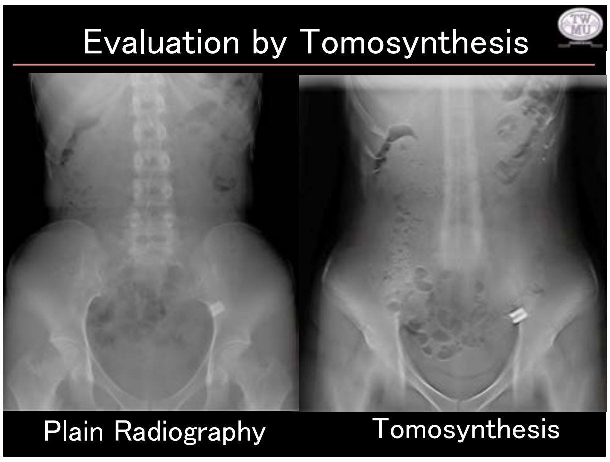


Fig. 9

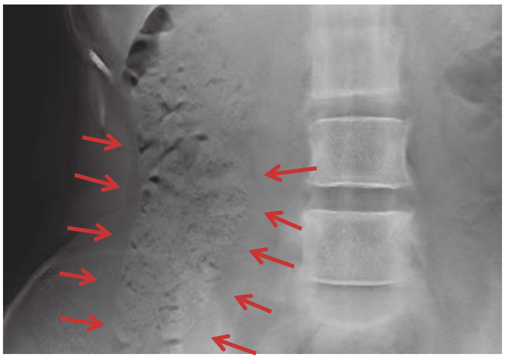


Fig. 10(a) Ascending Colon

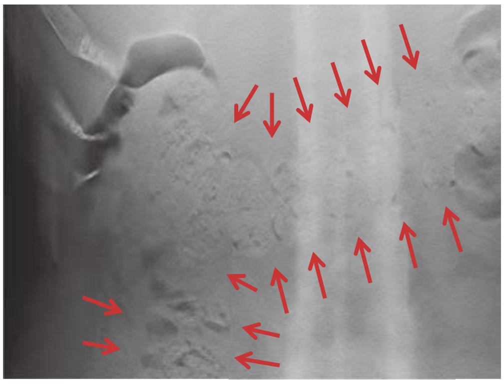


Fig. 10(b) Transverse Colon

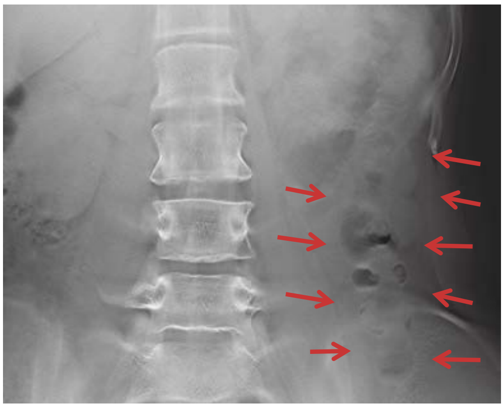


Fig. 10(c) Descending Colon

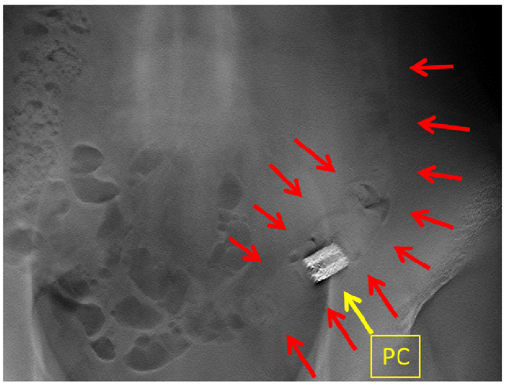


Fig. 10(d) Sigmoid Colon and PC

7. What Is Tomosynthesis?

Tomosynthesis takes multiple projection images in a single tomographic imaging operation and applies post-processing to reconstruct section images at the required depths. Tomosynthesis is less invasive; it requires approximately twice the X-ray exposure dose of plain radiography and one-tenth the dose for CT. Tomosynthesis is the promising low dose X-ray imaging method for evaluation of PC locations.

8. Conclusions

We reported the current situation and future possibilities for evaluating gastrointestinal tract patency using patency capsules. This is the first report using tomosynthesis for the patency evaluation of PC in gastrointestinal tract, and we will continue further investigations in the future.

Application of Tomosynthesis for Colon X-Ray Examination

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Takashi Nonaka

Mr. Takashi Nonaka

1. Introduction

Fussa Hospital is located in the western part of the Tama region of Tokyo. It functions as a general hospital with 316 beds and provides health care to local and regional communities.
The Department of Radiology has 12 full-time medical X-ray technologists and two full-time radiologists, who perform CT, MRI, various types of radiography, contrast examinations, image diagnosis, nuclear medicine examinations, as well as therapy, radiation therapy and IVR **(Fig. 1)**.

Fig. 1 External View of Fussa Hospital

The hospital was reopened in October of 2008 after renovations that saw the introduction of FPD systems in the majority of its image diagnosis systems (three general radiography systems, two fluoroscopy systems, one mammography system, one mobile X-ray system, and one angiography system). Of these systems, two of the fluoroscopy systems are Shimadzu SONIALVISION safire series, and used to perform various types of fluoroscopy examinations. One of these units is equipped for tomosynthesis and slot radiography **(Fig. 2)**.

Fig. 2 SONIALVISION safire Series

At Fussa Hospital, fluoroscopy examinations are used in a wide range of clinical departments, including surgery, orthopedics, urology, pediatrics, obstetrics and gynecology, and internal medicine. In these departments, the vast majority of examinations are surgery-related (including vascular system IVR), with two fluoroscopy systems fully utilized for this purpose.

2. Background

Although colorectal cancers in Japanese people were once thought to be relatively rare, they are among a number of cancer types for which rates of incidence have been increasing rapidly in recent years in Japan. After gastric cancers and lung cancers, by 2020 colorectal cancers are anticipated to account for the highest incidence in number of cases and rate of incidence of all cancers in Japanese men and women combined. The number of deaths due to colorectal cancer has more than doubled in the last 20 years and continues to increase, with colorectal cancers being particularly prevalent in Japanese women among whom it is the primary cause of cancer death.[1)]
Fussa Hospital performs a very large number of surgical procedures, surgery-related examinations and treatments, with many of these procedures pertaining to lower gastrointestinal tract.
Among those procedures, colon X-ray examinations are performed preoperatively as a matter of course, as well as for the purpose of medical examination.
When a colon X-ray examination is performed at Fussa Hospital, after routine radiography has been performed, three further overall images of the colon are taken in standing, supine, and prone positions.
These images are used to help in examining the entire colon in terms of positional and morphological matters, and are also requested by the gastrointestinal specialists who perform surgery. The 17-inch field-of-view of the SONIALVISION safire series allows observation of a wide area **(Fig. 3)**.

There are also the significant benefits of being able to acquire tomographic images of the entire colon **(Fig. 4)**.

Here is reported a study of the current and potential applications of tomosynthesis with the SONIALVISION safire series for colon X-ray examinations.

Fig. 3

Fig. 4 Tomosynthesis Image with 17 × 17 Field-of-View

3. Tomosynthesis

Previous tomography required significant time and effort to produce the images, and a lack of continuity between the tomographic images increased the number of scans required to observe a given sectional plane image, placing a large burden on the patient both in terms of time and exposure dose.

Using tomosynthesis, the data acquired with a single scan can, after applying filtered back protection (FBP) (a method of reconstruction commonly used in CT that creates high-contrast and sharp images with few artifacts by assuming cone-beams to be approximately parallel beam scans) and shift-and-add (SA) (determines a sectional plane by matching a conventional plain tomographic image down to individual pixels with the amount of movement and shifts their positions accordingly. SA has the demerit of producing significant artifacts, but creates images close in quality to those obtained with previous film section imaging) algorithms, produce a reconstructed image of any section in the area scanned with high spatial resolution. The workflow and parameter settings for tomosynthesis are shown in **Table 1**.

When parameter settings are programmed and ready to use, the imaging itself takes around 1–2 minutes and to obtain the tomographic images takes a further 4 minutes. Operation of the systems involved is very simple, and the minimal examination time means there is little burden on the patient.

Tomosynthesis Workflow

① **Confirm exposure field by fluoroscopy.**

↓

② **Choose a protocol. → SET**

↓

③ **Radiography (2.5 or 5.0 seconds)**

Total: Approx. 1–2 minutes

Transfer to workstation: 2 min

Automatic section reconstruction: 2 min

Tomographic Angles	40°, 30°, 20°, 8°
Tomographic Pitch	0.5, 1, 2, 3, 5, 10, 15, 20, 25 mm
Range of Section Reconstruction	0–250 mm
Tomography Time	Fast: 2.5 sec
	Slow: 5.0 sec
Acquisition Rate	High Res.: 15 fps
	Normal: 30 fps
Reconstruction Mode	Shift-and-add (SA)
	Filtered back projection (FBP)

Table 1 Tomosynthesis Workflow and Each Parameter Setting

4. Study Methods

To determine the optimum conditions for radiography and reconstruction, items (1) to (5) below were studied.

(1) Measuring the effective section thickness

Metal beads were used to measure the effective section thickness for each swing angle and each reconstruction filter. ImageJ was used to perform the analysis, and the full width at half maximum was measured from the profile of the metal bead from which an effective section thickness was calculated **(Fig. 5)**.

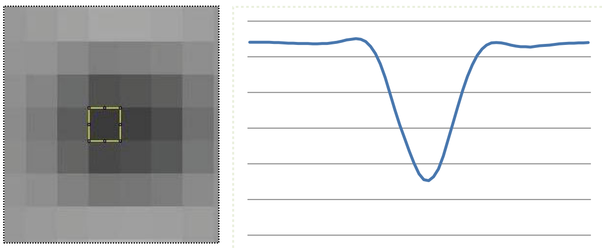


Fig. 5 Measuring the Effective Section Thickness

(2) Unique acrylic tube phantom evaluation

A unique acrylic tube phantom was used to investigate the ability to render an image with differing swing angles and reconstruction filters.

The acrylic was interlaminated and images were obtained in the directions shown in **Fig. 6**. The evaluation was made based on the profile curve.

(3) Measuring the exposure dose

The surface dose was measured at different acquisition speeds (slow or fast) and swing angles (8°, 20°, 30°, 40°).

(4) Evaluating rendering ability using a unique imitation colon phantom

A unique imitation colon phantom (hereafter colon phantom) was used to evaluate rendering ability in various ways **(Fig. 7)**.

(5) Exposure dose was measured at various tube voltages (80–120 kV) and rendering ability was evaluated (colon phantom) with the purpose of reducing the exposure dose.

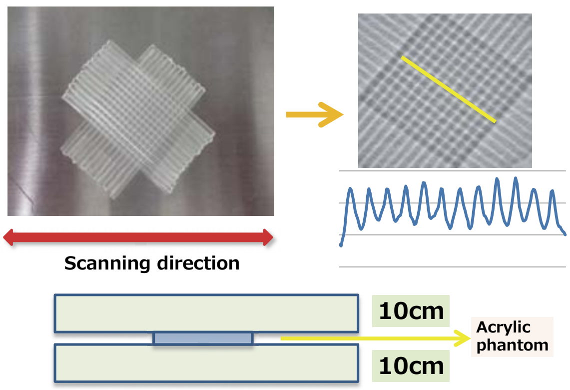


Fig. 6 Evaluation Using an Acrylic Tube Phantom

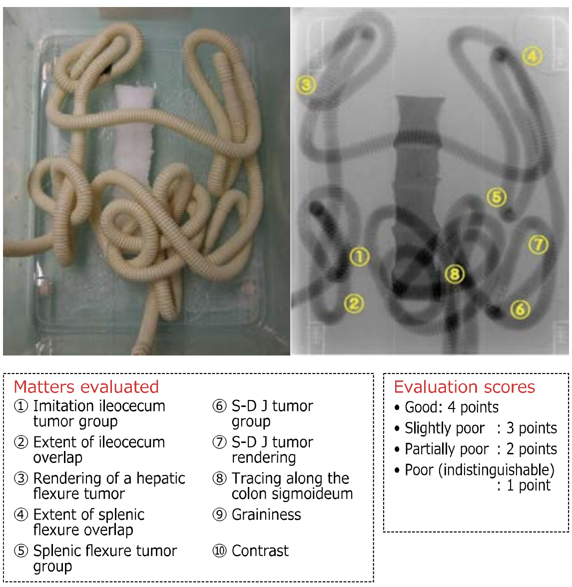


Fig. 7 Evaluation Using a Colon Phantom

5. Results

(1) Effective section thickness measurements are shown in **Table 2**.

The effective section thickness became progressively thinner as the reconstruction filter transitioned from "+ +" to "- -".

No major difference was observed between using swing angles of 40°, 30° and 20°. At a swing angle of 8°, the section thickness was thicker relative to the other angles.

Reconstruction Method	Swing Angle (°)	Reconstruction Filter	Section Thickness (mm)
FBP	40	Thickness + +	12.5
		Thickness +	9.5
		Thickness + –	7.5
		Thickness –	6
		Thickness – –	4.5
	30	Thickness + +	12
		Thickness +	10
		Thickness + –	8
		Thickness –	6
		Thickness – –	5
	20	Thickness + +	12.5
		Thickness +	9.5
		Thickness + –	8.5
		Thickness –	6.5
		Thickness – –	5.5
	8	Thickness + +	15
		Thickness +	12.5
		Thickness + –	11.5
		Thickness –	10.5
		Thickness – –	10

Table 2 Effective Section Thickness Measurement Results

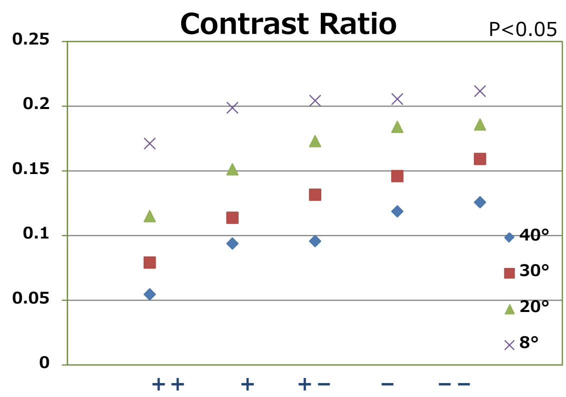


Fig. 8 Acrylic Tube Phantom – Contrast Ratio Plot

(2) Contrast ratios measured during evaluation of the acrylic tube phantom are shown in **Fig. 8**.

The contrast ratio was at its highest when the swing angle was 8° and with a reconstruction filter of "Thickness - -".

(3) Results of measuring the exposure dose are shown in **Table 3**.

Since the set acquisition speeds are 2.5 seconds on fast and 5.0 seconds on slow, the surface exposure on slow is double that on fast. No difference could be seen when varying the swing angle since when imaging is performed, the tomography time is matched to the angle (exposure on fast is for 2.5 seconds and exposure on slow is for 5.0 seconds, regardless of the angle).

Acquisition Mode	Acquisition Speed	Swing Angle (°)	Surface Exposure (mGy)
HighReso	SLOW	40	7.02
		30	7.22
		20	7.12
		8	7.05
	FAST	40	3.68
		30	3.49
		20	3.42
		8	3.59

Table 3

(4) Results of the colon phantom evaluation are shown in **Fig. 9**.

A large swing angle resulted in good rendering ability and a "- -" reconstruction filter also resulted in good rendering ability, but with strong contrast and excessive accentuation of edges that affected the ability to render the imitation tumor **(Fig. 10)**.

(5) Results of measuring the exposure dose at differing tube voltages are shown in **Table 4**, and an evaluation of rendering ability is shown in **Fig. 11** (swing angle: 40°, reconstruction filter: "+ -").

Although this is an obvious relationship, when the mAs level was reduced, the surface dose also reduced.

There was no major difference in ability to render the colon phantom at tube voltages of 80 kV or higher.

There was also no significant difference in the standard deviations calculated. Tomosynthesis images of the colon phantom are shown in **Fig. 12**.

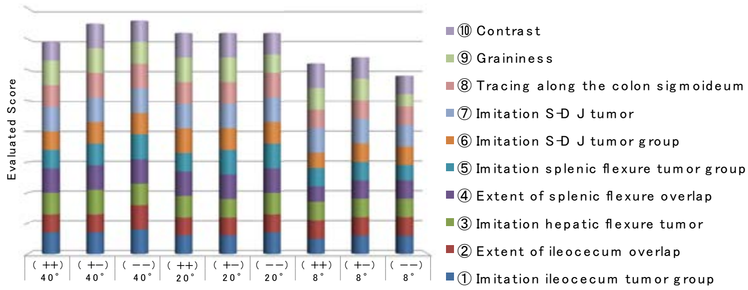


Fig. 9 Results of the Colon Phantom Evaluation

Tube Voltage (kV)	mAs Level	Surface Exposure (mGy)
80	5	13.96
90	2.5	9.583
100	1.25	6.226
110	0.63	3.675
120	0.5	3.48

Table 4

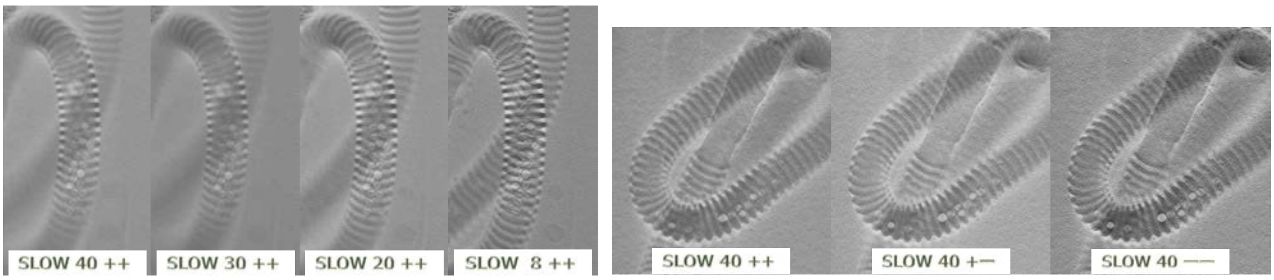
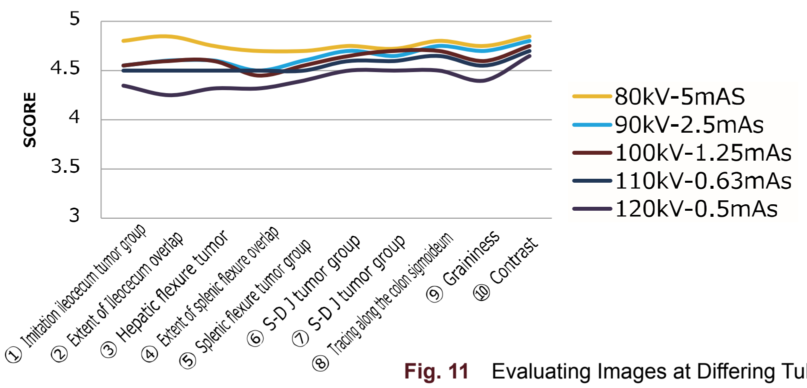


Fig. 10 Colon Phantom Images



$P<0.05$

Tube Voltage (kV)	mAs	Standard Deviation (SD)
80	5	586.179
90	2.5	622.143
100	1.25	612.982
110	0.63	604.092
120	0.5	594.872

Fig. 11 Evaluating Images at Differing Tube Voltages

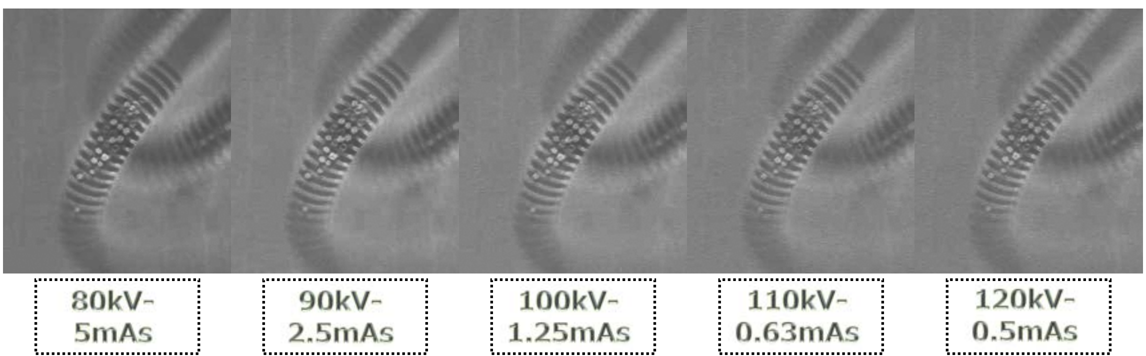


Fig. 12 Evaluation at Differing Tube Voltages Using the Colon Phantom

6. Discussion

Regarding the effective section thickness, the tomosynthesis reconstruction filter includes a low-pass filter that limits bandwidth. Section thickness is varied by increasing or reducing the strength of the bandwidth limitation. A setting of "Thickness + +" creates a strong limitation on bandwidth and increasing the section thickness, while "Thickness - -" creates a weak limitation on bandwidth that reduces the section thickness.
We were able to achieve good rendering of even very small shadows by using the appropriate reconstruction filter with the colon phantom.
Based on this study, a swing angle of 40° and the reconstruction filter "+ -" was optimum in terms of rendering ability and artifacts for a colon X-ray examination **(Fig. 13)**.

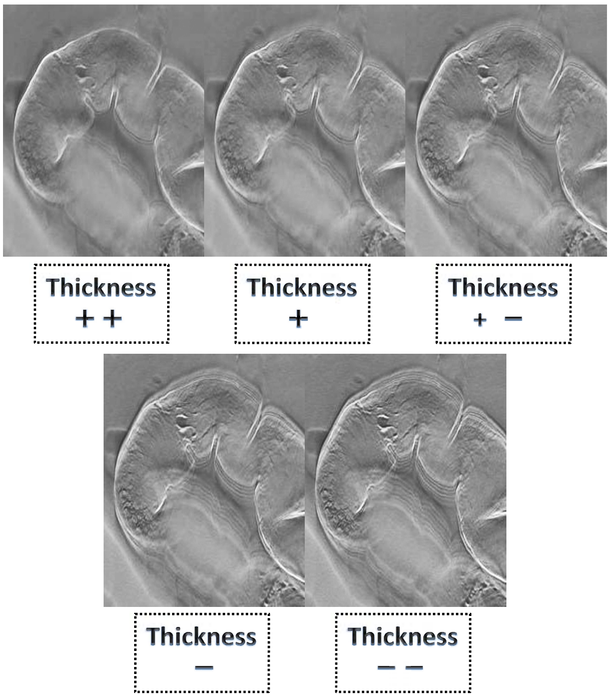


Fig. 13 Deference in Rendering Very Small Polyps Using Different Reconstruction Filters

With this type of examination, movement can also cause artifacts, so it is important to choose an acquisition speed (slow or fast) according to the status of the patient.
There are concerns that tomosynthesis increases the exposure dose to patients, but by increasing the tube voltage and reducing the mAs level, it is possible to reduce the exposure dose to that of conventional colon X-ray examinations. In this study, no significant difference in rendering ability was observed between different tube voltages when using the colon phantom, and we believe 100 kV or higher high-voltage radiography to be clinically useful. **Fig. 14** shows a workflow comparison for performing intestinal infusion without tomosynthesis, and after introducing the technique.
Total times of one tomosynthesis are 1-2 minutes and performing tomosynthesis does not adversely affect imaging times.
Tomosynthesis can be used to recognize lesions as well as create an image of the entire colon, reducing the risk of overlooking any clinical problems.
Clinical images are shown in **Fig. 15**. An elevated lesion can be seen in the colon sigmoideum, which is overlapped by the rectum on the image. Using tomosynthesis allows the area of this lesion to be rendered clearly.
The X-ray parameters are 100 kV and 1.25 mAs, which is high-voltage radiography but after a clinical assessment we believe this will pose no problems clinically.
An elevated lesion is observable in the SD junction in **Fig. 16**, while the small polyp in the colon sigmoideum was not observed by fluoroscopy. The elevated lesion and small polyp were easily observable using tomosynthesis.
X-ray parameters are 110 kV and 0.63 mAs.

	Previous Method	With Tomosynthesis
From Rectum to Colon Sigmoideum	6 to 8	6 to 8
Descending Colon	2	2
Splenic Flexure	2	2
Transverse Colon	2	2
Hepatic Flexure	2	2
Ascending Colon	2	2
Ileocecal Area	6	6
Overall Image	3	Tomosynthesis × 1
Examination Time	20min	20min

Fig. 14 Workflow for Intestinal Infusion Before and After Introduction of Tomosynthesis

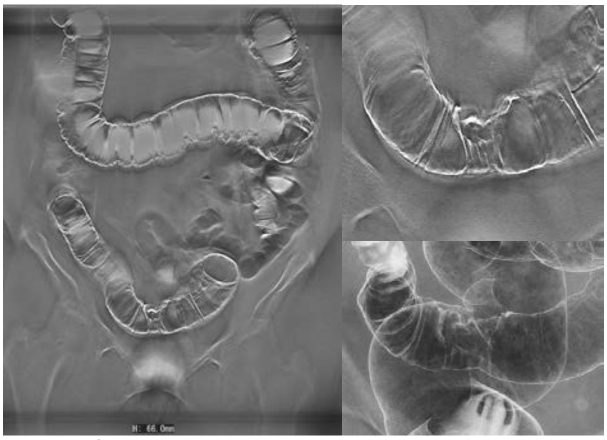


Fig. 15 Clinical Images

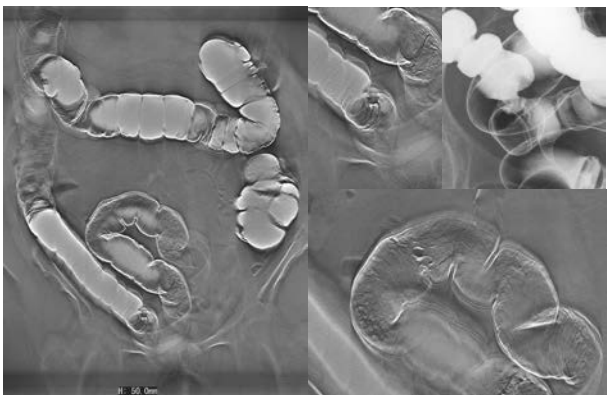


Fig. 16 Clinical Images

In terms of the future prospects for tomosynthesis, we believe action needs to be taken to actively make physicians aware of the technique. Tomosynthesis has the disadvantage relative to CT of only creating tomographic images in the scanning direction, and cannot create a three-dimensional reconstruction as with MPR, but considering the exposure time and exposure doses involved there is considerable potential for its application not only in the field of orthopedics where it sees the greater part of use present, but also in gastrointestinal contrast radiography as one example. The slow mode normally results in 74 views, but at this hospital and with a normal reconstruction pitch of 1 mm this number becomes around 100 images. The monitor display is an essential piece of equipment for observation when considering this amount of images, and we see the ancillary equipment used to read and interpret these images becoming more important with time.

7. Conclusion

Tomosynthesis is extremely effective for colon X-ray examination of areas with complex topographies and lesions. Furthermore, imaging of the entire colon is an effective way of making sure smaller lesions are not missed.

By using appropriate X-ray parameters, the exposure dose to the patient can also be reduced to amounts below plain radiography. We intend to perform further studies of tomosynthesis and actively pursue its adoption in the clinical environment.

This article is excerpted and rewritten based on presentations given at the 2011 Kanto & Koshinetsu Conference of Radiological Technologists, and the 2012 Conference of the Japan Association of Radiological Technologists.

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Applications of Tomosynthesis to Bronchoscopic Examinations

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Masahiro Nakajima

Introduction

Transbronchial tumor biopsies (TBTB) and CT-guided lung biopsies are performed for the definitive diagnosis of lung cancer. At present, approximately 200 transbronchial tumor biopsies are performed at this hospital each year. However, in some cases, positional confirmation under fluoroscopy can be difficult for diseases exhibiting faint shadows such as ground-glass opacity (GGO). While CT-guided lung biopsies offer excellent contrast, they can present surgical difficulties in the upper lung field. Combining tomosynthesis with the biopsy forceps and positional confirmation of lesions under fluoroscopy for transbronchial tumor biopsies simplifies the positional confirmation. To date, at this hospital we have jointly used tomosynthesis in examinations in approximately 50 cases.

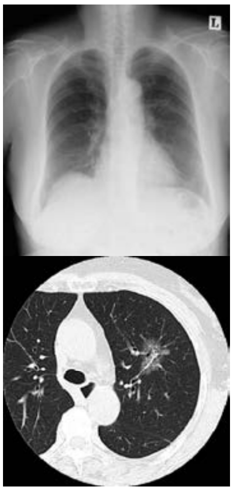


Fig. 1 GGO Case

Method

Tomosynthesis is used for transbronchial tumor biopsies in cases where positional confirmation by bronchoscopic examinations is difficult, including faint shadows such as ground-glass opacity (GGO) or lesions at the lung peripheries **(Fig. 2)**. In cases where tomosynthesis is used, chest tomosynthesis is performed to check that the biopsy forceps can reach the associated bronchial tube and to confirm the reconstruction position and reconstruction range. This allows the doctor to check images as rapidly as possible during the examination. In some cases, DICOM Viewer is used to create oblique images from these pre-tomosynthesis images to check the paths of the bronchial tubes **(Fig. 3)**. Pre-imaging is performed using the normal radiography conditions (Slow mode). However, the actual examination is performed in Fast mode to reduce X-ray exposure to the patient and shorten the breath-holding time **(Fig. 4).**

The radiography and reconstruction conditions are shown below.

(1) Radiography conditions

Pre-imaging: 120 kV, 1 mAs, 74 shots (Slow mode), 1 scan, 5 sec

TBTB imaging: 120 kV, 1 mAs, 36 shots (Fast mode), 1 scan, 2.5 sec

* Radiography conditions are adjusted according to the body thickness.

(2) Reconstruction conditions

Pre-imaging: Thickness - - Slice pitch 1 mm (0.5 mm, creating oblique images)

TBTB imaging: Thickness + - Slice pitch 3 mm

A thin slick thickness is set for pre-imaging to simplify positional confirmation of lesions. However, the slice thickness is increased and the slice pitch somewhat extended for reconstruction during the transbronchial tumor biopsy to ensure that the target region remains within the reconstruction range, as the reconstruction position may become displaced due to breathing or other causes.

Tomosynthesis imaging is performed when the biopsy forceps arrive and grasp the lesion. The surgeon can confirm images on the monitor in the examination room to confirm the biopsy **(Fig. 5)**.

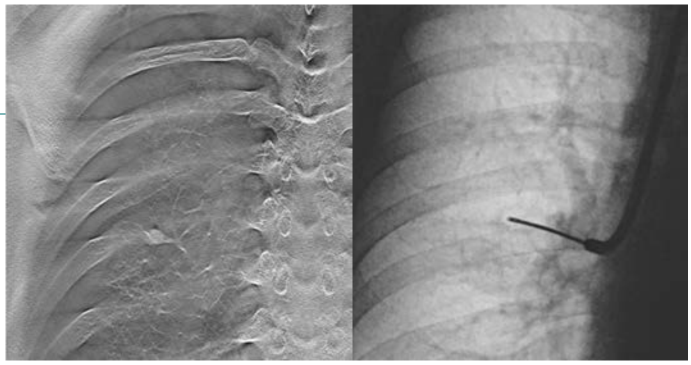


Fig. 2 Comparison of Fluoroscopic Image (Right) and Tomosynthesis Image (Left)

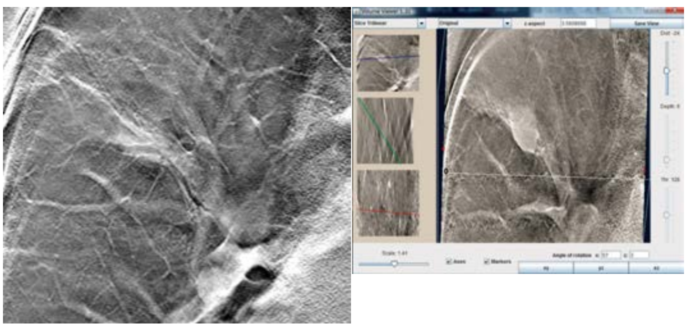


Fig. 3 MPR Display by DICOM Viewer

Fig. 4 Transbronchial Tumor Biopsy

Fig. 5 Confirming Biopsy Position

Results

Faint shadows such as ground-glass opacity (GGO) could not be observed by positional confirmation fluoroscopy. However, tomosynthesis tests with phantoms were able to observe nodules with -600 CT value **(Fig. 6)**. Positional information in the body-thickness direction can be reconstructed up to 0.5 mm reconstruction slice pitch. Changing the slice pitch according to the nodule size makes observations easier. Using filters to reduce the metal artifacts during image reconstruction can restrict artifacts due to the biopsy forceps to facilitate observations **(Fig. 7)**. During actual examinations, tomosynthesis and image reconstruction are performed at the position where the lesion is thought to be grabbed by the biopsy forceps. Previously, during a bronchoscopic examination, the side station images could be displayed on the console monitor only. However, the monitor switching function can display these images on monitors in the examination room. The images can be displayed on monitors in the examination room after approximately 2 minutes for reconstruction of 15×15 images. As the reconstruction time differs according to the image size, the time can be reduced by decreasing the size of the image. Tomosynthesis imaging is performed to easily confirm that the biopsy forceps have arrived and grasped the lesion. In particular, tomosynthesis simplifies positional confirmation of the biopsy forceps and the lesion in situations where positional confirmation by fluoroscopy is not possible, such as biopsies at the peripheries. The height information in the body-thickness direction permits reconfirmation by image reconstruction at the position of the peripheral bronchial tubes to facilitate reentry of the biopsy forceps.

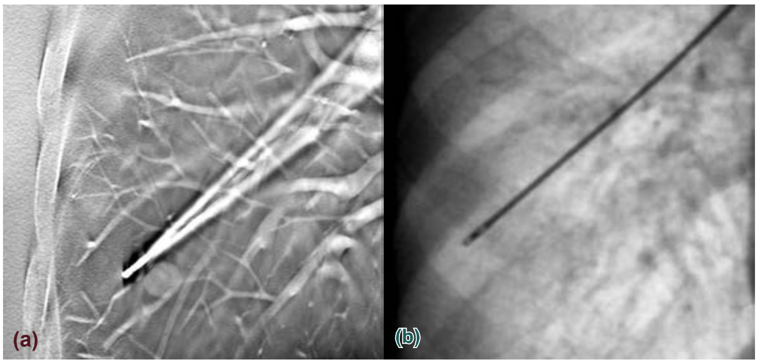


Fig. 6 Evaluation of -600 CT Value Nodule
(a) Tomosynthesis Image, **(b)** Fluoroscopic Image

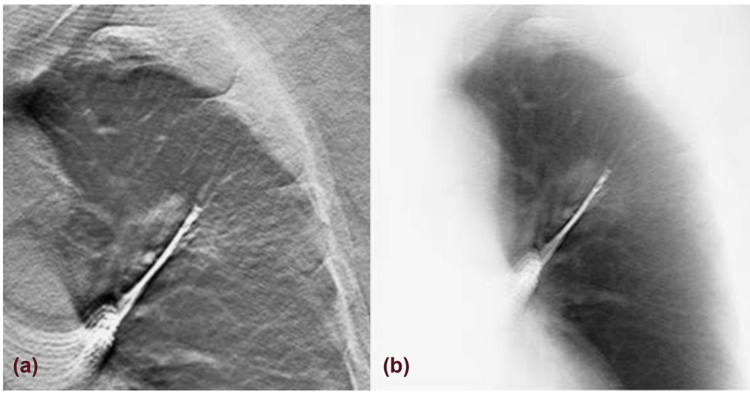


Fig. 7 Comparison of Tomosynthesis Filters
(a) Tomosynthesis Image **(b)** Tomosynthesis image using metal-artifact filter

Discussion

As tomosynthesis simplifies positional confirmation for transbronchial tumor biopsies and permits observations around the peripheral bronchial tubes during re-examinations, it is expected to enhance the rate of lesion biopsies. It may also be able to reduce the exposure dose for CT-guided biopsies. However, one scan takes 2.5 seconds for tomosynthesis imaging, even in Fast mode. With the current time resolution, displacement of the reconstruction position may cause blurring of the image for biopsies near the heart due to cardiac motion, which can make it difficult to identify lesions with faint shadows. Therefore, enhanced time resolution and electrocardiogram-synchronized image reconstruction methods to improve the image quality remain to be investigated in the future.

Clinical Experience Using the Slot Scan Function with an X-Ray Fluoroscopy System

Mr. Nobuhito Handa

Fukushima Medical University Hospital, Department of Radiology
Nobuhito Handa

1. Introduction

Fukushima Medical University is located in a green, natural environment in the north of Fukushima Prefecture. The university comprises a School of Medicine based around the old Fukushima Women's Medical School that was founded in 1944 and a School of Nursing that opened in 1998, Graduate School, and Fukushima Medical University Hospital.
As the result of an ongoing drive for change and a desire to create a more open university, it became an independent administrative corporation in April 2006 — Fukushima Medical University.
Fukushima Medical University Hospital offers 778 clinical beds and handles an average of 1795 outpatients per day (fiscal 2007). It remains both a higher education facility and a regional center for advanced medical technology.
The Department of Radiology offers five FPD R/F systems (two direct conversion and three indirect conversion). A Shimadzu SONIALVISION safire II system was introduced in March 2008 as an upgrade for an existing system. A major factor in selecting this system was the wide-field (17" × 17") FPD that permits kidney-ureter-bladder (KUB) radiography.
This paper reports on the utility and problems with the SONIALVISION safire II Slot Scan radiography application.

2. Long-Length Imaging

Long-length imaging is an essential radiography technique in the field of orthopedic surgery for the diagnosis of scoliosis and alignment measurements on the full length of the lower limbs. At this hospital, we conduct radiography with multiple IPs loaded in a long-length cassette and join the images together when reading them.
The SONIALVISION safire II system Slot Scan function conducts radiography with the X-ray beam collimated into a slit by moving the X-ray tube and FPD at constant speed in the body-axis direction and then reconstructs the information into a long-length image **(Fig. 1)**.
The radiography modes include HS (High Speed) and HQ (High Quality) in addition to F (Frontal) and L (Lateral). The radiography center height, slot width, and speed of movement differ according to the mode. In the HS mode, the imaging chain moves at 150 mm/sec and acquires data with a 6 cm slot width at the radiography center height. In the HQ mode, the imaging chain moves at 75 mm/sec and acquires data with a 4 cm slot width at the radiography center height. A reference height is set to achieve appropriate image stitching during image reconstruction.

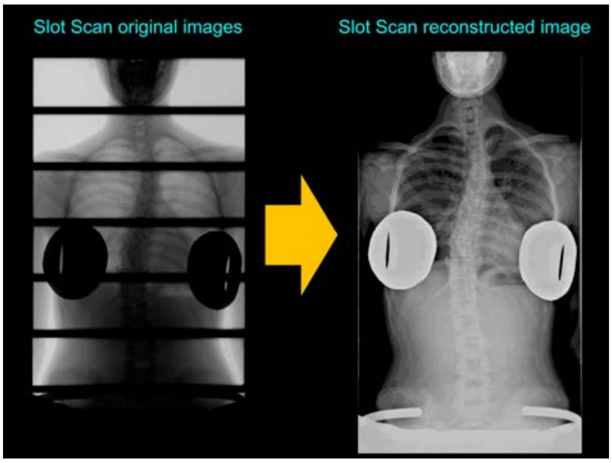


Fig. 1

Long-length imaging is possible using FPD fluoroscopy systems from other manufacturers, in addition to the SONIALVISION safire II. The imaging method differs from manufacturer to manufacturer. Company A adopts the same parallel movement of X-ray tube and FPD used by Shimadzu, whereas Company B tilts the X-ray beam such that the magnification is identical in the overlapping regions of the two images **(Fig. 2)**. Before we introduced the SONIALVISION safire II system, we already had instruments that offered long-length imaging functions. However, due to the complexity of setting radiography conditions and the difficulty in understanding the range of coverage, they proved inadequate to substitute for conventional cassette radiography and were not used for routine radiography examinations. However, the SONIALVISION safire II Slot Scan function is easy-to-use and frequently used for routine radiography.

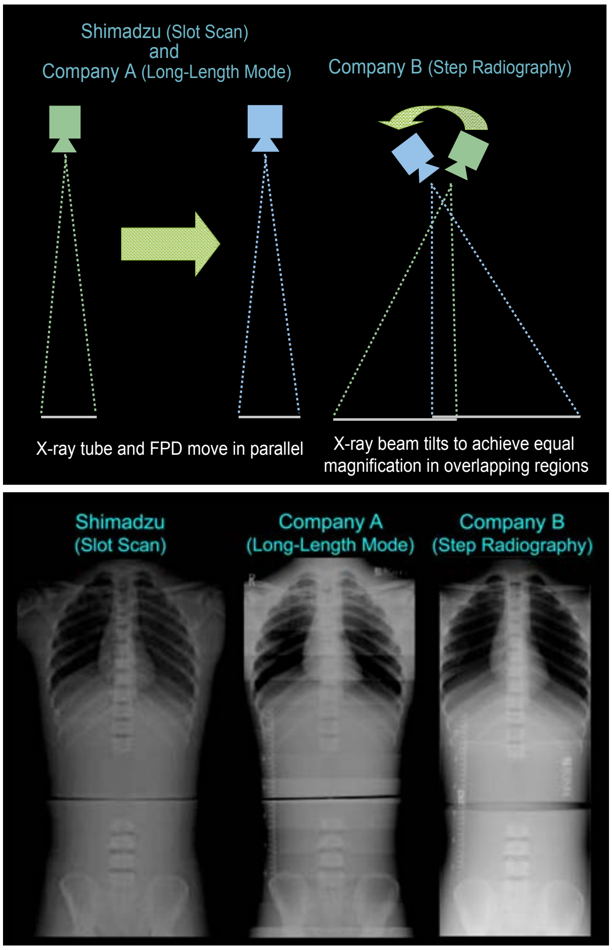


Fig. 2

3. Slot Scan Ease-of-Use

Fig. 3 shows flowcharts of the work flow for cassette radiography and Slot Scan radiography. The conventional CR long-length imaging operation is complex. It requires switching the IP and reading the image after every exposure. Patient throughput is poor, as the patient has to wait in the radiography room while the images are being checked. Conversely, Slot Scan radiography requires just the start and end positions to be set. Images can be checked immediately after radiography is complete, which reduces the examination time and improves efficiency.
Conventional CR long-length imaging is difficult for patients who have trouble standing, as it is difficult to achieve adequate SID from the table and to maintain the long imaging field. It is also difficult in cases where a wide imaging field is required, such as patients with severe scoliosis and radiography of both legs simultaneously. With its 1400 mm FPD movement range and 430 mm wide coverage, Slot Scan flexibly accommodates a diverse range of radiography examinations **(Fig. 4)**. As many scoliosis patients are young, it is important to reduce the X-ray exposure dose over follow-up examinations over many years.
Slot Scan exploits the wide dynamic range of the FPD to perform radiography with a lower X-ray exposure dose than the conventional method.

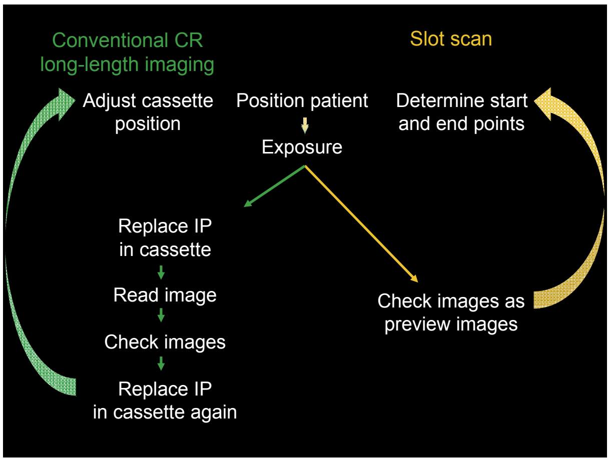


Fig. 3

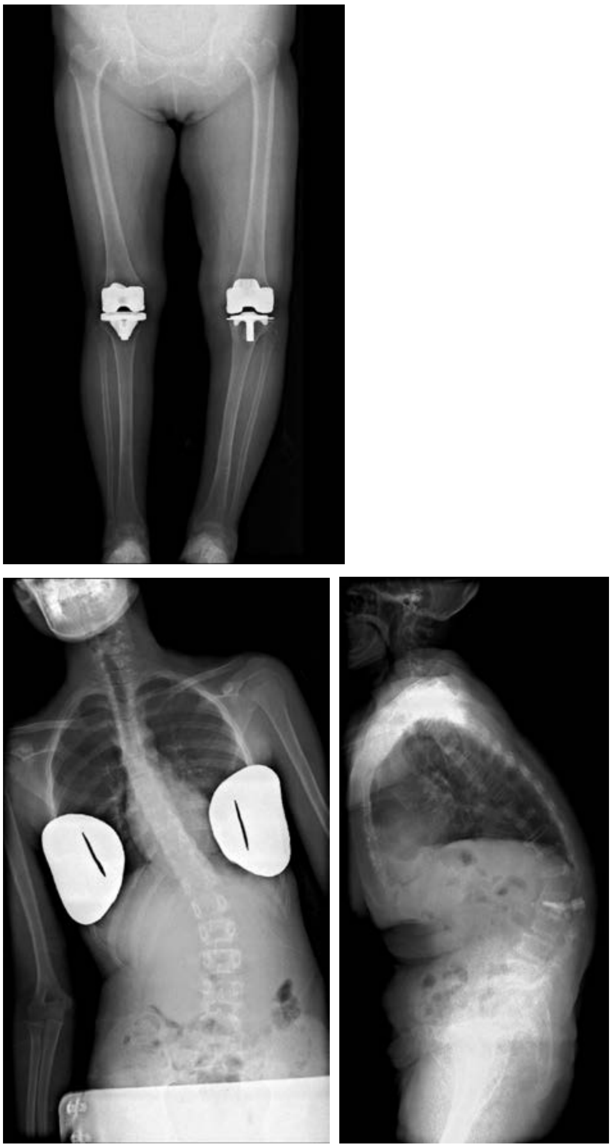


Fig. 4

4. Jointly Using Slot Scan and Conventional Method

Long-length images are used for diagnosis of scoliosis and follow-up examinations. However, since the introduction of the SONIALVISION safire II Slot Scan, we have been concerned that the Cobb angle (that expresses the angle of curvature of the spine) obtained by Slot Scan may differ from Cobb angle from images obtained by the conventional method, because the method of linking the images differs. Slot Scan differs from the conventional method because the reference height is set above the tabletop and the overlap of the various Slot Scan images is calculated to link the images together.

We produced a phantom to evaluate any discrepancy between the Cobb angle measured from the conventional method and from Slot Scan measurements **(Fig. 5)**. The phantom comprised plastic cases filled with caulking that were arranged as simulated vertebrae. Measurements were performed by doctors and technologists. Both the conventional method and Slot Scan produced approximately the same measured results, confirming that no problem arises when using both Slot Scan and the conventional method.

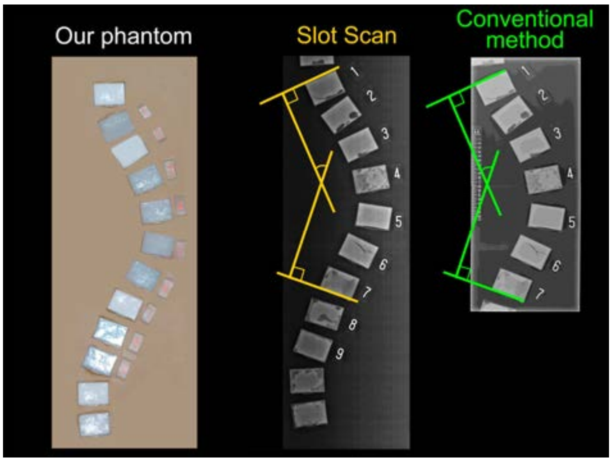


Fig. 5

5. Precautions During Radiography

Using Slot Scan, the position of interest is adjusted to the reference height during image reconstruction to ensure accurate measurements. However, appropriate images cannot be obtained if the reference height differs from the area of interest. **Fig. 6** shows Slot Scan images of acrylic rods positioned at different heights above the tabletop. The image is reconstructed correctly for the acrylic rod at the reference height. For rods higher than the reference height, the stitched positions are more separated in the reconstructed image. For rods lower than the reference height, the stitched positions are more overlapped in the reconstructed image. Due to such artifacts at the stitched positions due to effects of the cone angle on objects at different heights from the reference height, it is important to accurately set the reference height for image reconstruction. Such effects occur readily at thicker parts of the body, such as the shoulder or pelvis. It is thought that Slot Scan reduces the effects of the cone angle by collimating the X-ray beam into a slit. However, in cases with high body thickness, such as lateral radiography of the full spine, appropriate condition settings and image reconstruction are required to further reduce these effects, such as using a combination of the longest possible SID and the HQ mode that has a narrow cone angle.

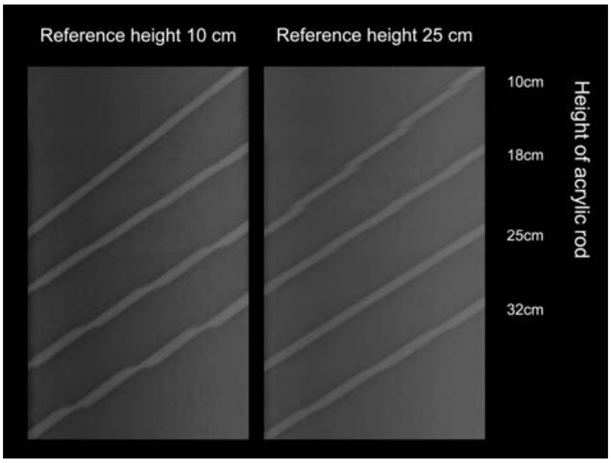


Fig. 6

In some cases a surplus or deficiency of X-ray dose can occur in images taken with the same radiography conditions, such as at the cervical spine and other low-body-thickness regions and at the shoulder, pelvis, and other high-body-thickness regions in lateral radiography of the full spine. Ideally, radiography should be conducted with the optimal X-ray dose at each region. Differences in radiography conditions can result in unnatural reconstructed images.

Changing the radiography conditions for each slot could produce natural-looking images to further improve the utility of this function for long-length imaging.

6. Conclusions

With its easy operation and excellent patient throughput, Slot Scan could replace cassette radiography. Unfortunately, as it cannot be used during other fluoroscopic examinations, it still has to be used in conjunction with the conventional method. I hope that we can use it more effectively in the future.

However, as Slot Scan operates with fixed radiography conditions, it cannot handle changes in body thickness and this can result in a surplus or deficiency of X-ray dose. This problem and the artifacts that occur at positions away from the reference height need to be resolved in the future. The Slot Scan function satisfies a range of clinical requirements and I anticipate that it will become increasingly effective for long-length imaging.

Utility of Slot Radiography and Epicondylar View After Implant Arthroplasties

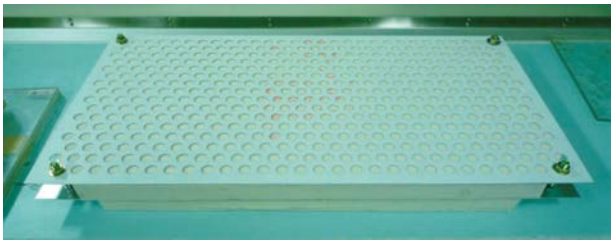
Department of Radiology, NTT East Corp. Sapporo Hospital
Kazuya Goto

Aim

Since spring 2007, this hospital has used slot radiography by SONIALVISION safire mainly for radiography of the lower extremities before and after total knee arthroplasties (TKA). Conventionally, radiography was performed using CR long-view radiography cassettes (three 14 × 14-inch cassettes). However, slot radiography offers smooth, continuous images in the standing or supine posture and easily produces seamless long images for more efficient examinations. Slot radiography performs imaging using parallel motion of the FPD and an X-ray beam collimated into a slot. Due to the different geometrical positional relationship between the subject and the detector, slot radiography produces different image distortion from long-view radiography (CR). The tests we performed to compare and evaluate these methods are reported below. Special radiography techniques mastered on this system, such as the epicondylar view for rotational alignment in TKA, are discussed.

Method

1. A phantom **(Fig. 1)** was made of a low-absorbance medium sandwiched between two aluminum punched metal panels. Slot radiography and long-view radiography (CR) images of this phantom were compared.
   1) Punched metal panel specifications:
   45 cm × 90 cm panel size, 2 mm thickness, 2 cm hole diameter, 3 cm hole pitch
   2) Arrangement of punched metal panels and low-absorbance medium:
   Punched metal panels were placed on top of low-absorbance medium on the tabletop
   3) Geometrical conditions for slot radiography:
   High-quality mode, frontal view, SID = 120 cm
   4) Geometrical conditions for computed radiography (CR):
   SID = 250 cm, three 14 × 14-inch IPs
2. Method for Epicondylar View Radiography **(Fig. 2)**
   1) Set the tabletop horizontal. Lie the patient down and restrain. Tilt up the tabletop.
   2) Fluoroscopic images are quickly taken of each knee separately while rapidly adjusting the imaging angle for each knee.
   3) After TKA, radiography is performed after checking accurate fluoroscopic frontal images.
   4) Compare with CT images with respect to presurgical planning for femoral rotational alignment.
   5) Investigate the left-right flexion gap symmetry in the knees-bent position.



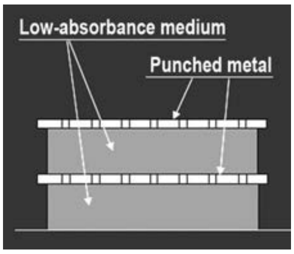


Fig. 1

Restrain supine patient and then tilt up the tabletop

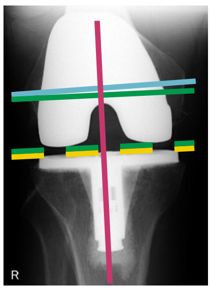


Fig. 2 Epicondylar View by SONIALVISION safire

Results

With CR long-view radiography, the holes near the center appear as single holes. The concentric images become more distorted as the distance from the center of the image increases. However, with slot radiography, almost no image distortion could be confirmed in the craniocaudal direction and the image distortion in the R-L direction was constant along the craniocaudal axis. The full-length image of one lower limb can be seen to offer extremely low vertical and horizontal distortion compared to plain radiography **(Fig. 3)**.

While the posteroanterior (PA) view is used for the epicondylar view with plain radiography, the anteriorposterior (AP) view is used with this system. This system is highly regarded by orthopedic surgeons, as imaging can be performed using rapid fluoroscopy to change the angle for each leg separately. Although these images are used for rotational alignment, they are in no way inferior to X-ray CT images **(Fig. 4)**.

The epicondylar view from the SONIALVISION safire is considered to have utility for post-TKA observations, since the strong metal artifacts occur in post-TKA CT observations.

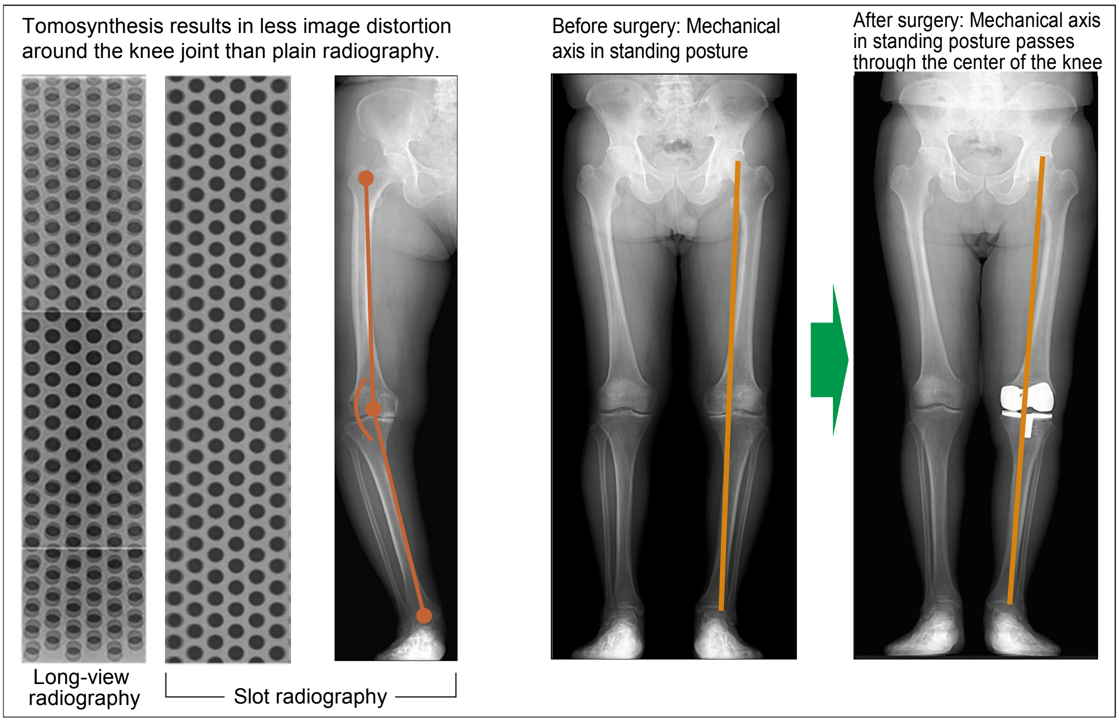


Fig. 3

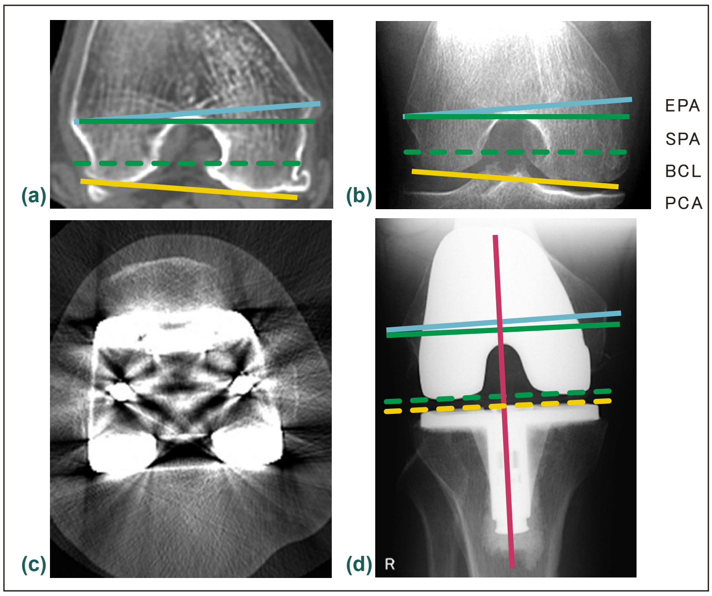


Fig. 4 Comparison of Femoral Rotational Alignment (before and after surgery)

Before surgery: **(a)** X-ray CT, **(b)** SONIALVISION safire

After surgery: **(a)** X-ray CT, **(b)** SONIALVISION safire

Discussion

Distortion affects CR long-view radiography, as the vertical and horizontal angles from the focal point increase toward the corners of a long cassette. Slot radiography produces little distortion, however, as the slit moves parallel to the imaged object and the image is back-projected to the height of the surface of the object.

In addition to this slot radiography, we introduced other radiography methods that are safer and more convenient than conventional plain radiography, such as the epicondylar view used for measurements for femoral rotational alignment before and after total knee arthroplasty (TKA) surgery.

Experience of Using Slot Radiography
– Experimental Use for Lower Extremity Venography –

Department of Radiology, Fussa Hospital
Shigeji Ichikawa

Mr. Shigeji Ichikawa

1. Introduction

Our hospital is a core hospital located in the western part of the Tama Area, which lies within the jurisdiction of Tokyo Prefecture. In October 2008, we reopened following extensive renovations **(Fig. 1)**. Although the final opening of the hospital is scheduled for February 2010, the hospital functions are already operating at a level of about 80%. The new hospital, which will have 316 beds at the time of the final opening, plays a part in providing medical care to residents of the local area. At the time of renovation, the Department of Radiology arranged the examination rooms and arranged and selected equipment in consideration of the circulation of patients and staff. This was conducted in accordance with the hospital's philosophy and was based on several years of consideration, reflecting a desire to develop medical care in a way that benefits patients and, in particular, to minimize examination waiting times (i.e., by improving throughput) and to minimize the burden on patients (i.e., by reducing examination times).

Nearly all systems (general radiography systems, radiography/fluoroscopy systems, angiography systems, and mammography systems (scheduled for introduction in 2010)) other than those for CT, MRI, nuclear medicine, and treatment are equipped with FPDs. As general radiography systems, we introduced three standing-position and three supine-position models of Shimadzu Corporation's RADspeed safire **(Fig. 2)**. Also, as R/F systems, we introduced two of Shimadzu's SONIALVISION safire II systems **(Fig. 3)**, and are fully utilizing them on a daily basis.

Fig. 1 External View of Our Hospital

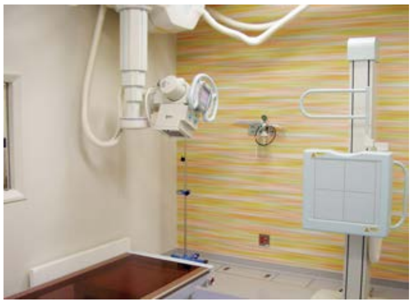


Fig. 2 Shimadzu RADspeed safire General Radiography System

Fig. 3 Shimadzu SONIALVISION safire II R/F System

2. Reasons for Introducing SONIALVISION safire II

At our hospital, surgical examinations are common and fluoroscopy is often used for long periods. It was therefore desirable to create an environment allowing examinations to be performed with as low a dose as possible. In comparison with other companies' FPD systems, SONIALVISION safire II produces relatively high-quality images with a relatively low dose, and also facilitates greater ease of use with aspects such as adjustment of the SID and changes in the F.O.V. size. Regarding radiography, this system is equipped with a large 17 × 17-inch FPD, and can support urological examinations by producing images of the entire abdominal area. We also conduct lower extremity venography over an extended range. For this purpose, it was necessary to create an environment allowing the entire lower extremity area to be captured with a single imaging operation and, after long consideration, we decided to use the long-view imaging function (hereafter referred to as “slot radiography”), which is an additional function of SONIALVISION safire II. The main reasons for our choice were the simple operability, the high quality, and the ability to perform serial radiography. We were also impressed by the ease and speed of image processing, and felt that this function could help us create a patient-friendly examination environment.

Here, I report on our experiences with this system, centering on lower extremity venography performed with slot radiography. Because of space restrictions, I focus mainly on frontal views.

3. Principle of Slot Radiography

In slot radiography, the X-ray tube and FPD move simultaneously at a constant speed in parallel with the longitudinal axis of the table, and data is acquired. There are two acquisition methods that can be used selectively in accordance with the objective: HS mode (150 mm/sec) prioritizes speed and HQ mode (75 mm/sec) prioritizes image quality. Operation is simple and imaging can be executed simply by pressing three buttons. The same region can be imaged again simply by pressing the [SET] button, a feature that further enhances operability **(Fig. 4)**. The acquired data is sent to a special-purpose side station (work station), where image processing is performed. This consists of the extraction of the effective portion of each frame from the acquired images and the joining of the overlapping parts to produce one long-view image. It takes approximately 15 sec in automatic processing mode following the completion of imaging. Because of the parallel movement of the longitudinal imaging system during data acquisition, X-rays are incident on the subject in an almost perpendicular direction, making it possible to obtain images with little distortion, and which facilitates highly precise measurement **(Fig. 5)**.

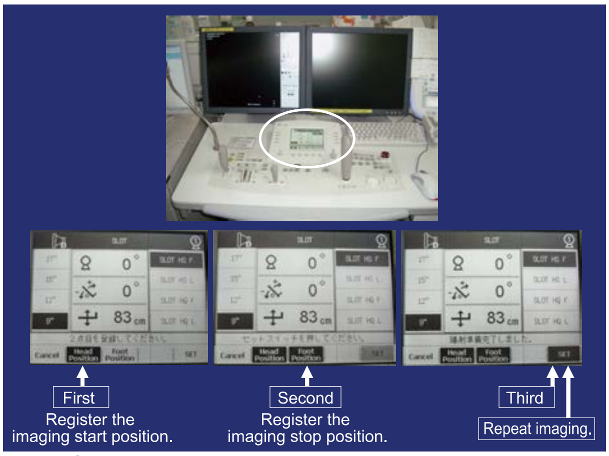


Fig. 4 Slot radiography can be executed simply by pressing three buttons.

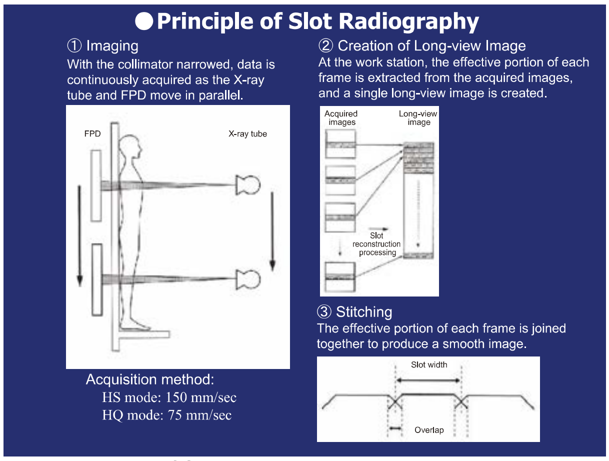


Fig. 5 Principle of Slot Radiography

4. Lower Extremity Venography

Objective: Diagnosis of varicose vein and vein thrombosis in lower extremities

Technique:

(1) The lower extremity to be examined is warmed for 15 minutes (e.g. gentle heating at 40 °C).

(2) The blood supply to the ankle joint was interrupted and a contrast medium is injected via the dorsal venous arch of the foot for 60 sec.

(3) After injection is completed, the lower extremity is imaged (early phase and delayed phase) in the standing position with two methods (“ant” and “lat”).

* Contrast medium: Nonionic iodinated contrast medium
Volume: 50 mL
(Quantity of iodine: 350 to 370 mg)

Varicose veins in lower extremities:
The veins in the lower extremities consist of deep veins, superficial veins, and communicating branches (or “penetrating branches”) that connect them. A “varicose vein” is a superficial vein that has expanded to form a bulge. They mainly occur in the calf area, and form a meandering path over the surface of the skin. There are valves in veins that stop blood flowing backwards, and it is believed that, for some reason, these valves cease to function normally, causing pressure to build up inside a vein, and ultimately producing a bulge when it becomes impossible to withstand this pressure. It is thought that the main causes of varicose veins in daily life include work that involves long periods of standing, childbirth, and aging. It is more common in women.

Deep vein thrombosis:
“Deep vein thrombosis” describes the state that occurs when a thrombus is created for some reason in a deep vein of a lower extremity, causing the flow of blood to stop completely. If a thrombus enters the lungs via a blood vessel, a blood vessel in the lungs may be blocked, and this may lead to a life-threatening condition. This phenomenon has recently become well known as “economy class syndrome”. It is more common in women.

5. Appropriate X-Ray Tube Voltage for Slot Radiography

The lower extremities contain both thick parts, such as the femurs, and thin parts, such as the ankle joints, and in order to create images, it is necessary to use an X-ray tube voltage that is suitable for both extremes. **Fig. 6** and **Fig. 7** show data based on evaluations of the relationship between thickness (i.e., subject thickness) and X-ray tube voltage using a Burger phantom and R1 micro chart, respectively. It can be seen from this data that the evaluation stabilizes around 100 kV.
Also, in visual evaluation that we performed using a “home-made” phantom, evaluation was good around 100 kV **(Fig. 8)**. In evaluation based on different modes (HS and HQ), there did not seem to be any significant difference **(Fig. 9)**. In clinical application, because there is great variety of subject thicknesses, at our hospital, we use the thickness of the center of the femur as a standard for setting exposure conditions.

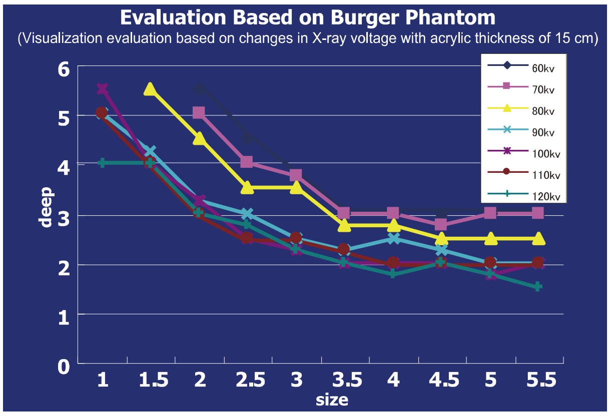


Fig. 6 Results of Visualization Evaluation Based on Changes in X-Ray Voltage with a Burger Phantom

Evaluation of Resolution Based on R1 Micro Chart
(Relationship between X-ray tube voltage and phantom thickness)

<phantom thickness>

X-ray tube voltage [kV]	5 cm	10 cm	15 cm	20 cm
60	2.0	1.5	1.0	0.5
70	2.0	2.0	1.0	0.5
80	2.0	2.0	1.25	0.5
90	2.25	2.0	1.5	0.8
100	2.25	2.5	1.5	0.8
110	2.5	2.5	1.75	1
120	2.5	2.5	2.0	1

Fig. 7 Results of Evaluation of Relationship Between Subject Thickness and X-Ray Tube Voltage Based on R1 Micro Chart

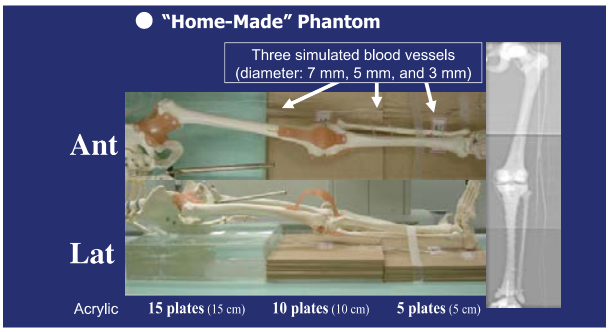


Fig. 8 “Home-Made” Phantom Used for Visual Evaluation

Image Evaluation Based on Phantom
Comparison of **HS** (150 mm/sec) and **HQ** (75 mm/sec) Mode

		HS	HQ
Groin		3.1	3.4
Knee joint		—	—
Ankle joint		3.3	3.6
Femur	Simulated blood vessel (7 mm)	4	4
	Simulated blood vessel (5 mm)	4	4
	Simulated blood vessel (3 mm)	3	3.1
Knee joint	Simulated blood vessel (7 mm)	—	—
	Simulated blood vessel (5 mm)	—	—
	Simulated blood vessel (3 mm)	—	—
Lower leg	Simulated blood vessel (7 mm)	3.6	4
	Simulated blood vessel (5 mm)	4	4
	Simulated blood vessel (3 mm)	3.6	4

Significant difference (-)

Fig. 9 Results of Visual Evaluation for Different Imaging Modes Based on “Home-Made” Phantom

6. Image Processing for Slot Radiography

We considered “G” (gamma correction curve) with respect to image processing. This system has three types of image processing curve for slot radiography. In evaluation based on the “home-made” phantom, it was established that the G2 curve shown in **Fig. 10** was optimal.
The thickness of lower extremities can exceed 20 cm in thick parts and be less than 5 cm in thin parts. In order to maintain good image quality for both extremes of thickness, it is essential to select a gamma curve that is relatively flat overall. The G2 curve has a relatively low inclination at intermediate levels, and ensures image processing that facilitates easy observation from low-concentration areas to high-concentration areas. It cannot be denied, however, that because of its relative flatness, the contrast is somewhat insufficient for the shadows of fine blood vessels. This problem can be solved using “E” (edge enhancement) processing. Enhancing the outline of shadows makes them easier to observe. Although we have not conducted a comprehensive investigation of this aspect, we use a setting of E3 (“quite strong”) at our hospital.
In a physical evaluation of image quality based on differences in mode, HQ mode was found to be slightly better. In clinical evaluation, however, there did not seem to be any significant difference. Regarding the image evaluation of slot radiography, because the imaging system is moving, there is some degree of blurring. It is conjectured that this blurring is the reason why there is not much difference in image quality between the various sets of data.
There are also imaging parameters such as AWC and DRC. We did not, however, conduct an investigation of these parameters on this occasion and so I will not comment on their relevance.

● Visual Evaluation of "G" (Evaluation Based on "Home-Made" Phantom)

		G1	G2	G3
Groin		3.1	3.4	2.2
Knee joint		—	—	—
Ankle joint		3.3	3.6	3.3
Femur	Simulated blood vessel (7 mm)	4	4	2.2
	Simulated blood vessel (5 mm)	4	4	3.3
	Simulated blood vessel (3 mm)	3	3.1	3.3
Knee joint	Simulated blood vessel (7 mm)	—	—	—
	Simulated blood vessel (5 mm)	—	—	—
	Simulated blood vessel (3 mm)	—	—	—
Lower leg	Simulated blood vessel (7 mm)	3.6	4	4
	Simulated blood vessel (5 mm)	4	4	3.5
	Simulated blood vessel (3 mm)	3.6	4	3.5

Points 4: Very good 3: Good 2: Poor 1: Very poor

Fig. 10 Results of Visual Evaluation for "G" (Gamma Correction Curve) Based on "Home-Made" Phantom

7. Comparison with Conventional Examination Methods

In conventional lower extremity venography, four long-view cassettes were used with an F/S system. Because the examination was performed on the floor, no significant burdens were observed with respect to changes of the patient's posture. In examinations performed with slot radiography, however, because of the movement of the X-ray tube and FPD, there are restrictions on the position of the patient, and the footstool must be set at quite a high position. This puts quite a large burden on the patient and is the only disadvantage of this system. Great care is required when changing the posture of the patient on the footstool, which is approximately 30 cm square. HS mode, which prioritizes time, is used in consideration of the influence of movement.

Regarding image processing, films obtained with the conventional method had to be developed in a dark room, which took approximately 15 minutes. With this system, however, image processing is performed quickly on the work station. I feel that this is a great advantage.

Regarding dose, slot radiography is possible with a smaller dose than that required with the conventional method did **(Fig. 11)**.

Because of the significant reduction in image processing time, it has been possible to reduce the overall examination time by about 20% to 30%.

Actual slot radiography images obtained in lower extremity venography are shown in **Fig. 12**.

Comparison with Conventional Method (F/S)

Examination posture	Conventional method	Examination performed with extended system in general radiography room, allowing it to be performed on the floor, and making it easy to change posture.
	Slot radiography	Examination performed at height of 70 cm above floor, making posture changes more difficult, and increasing the burden on the patient.
Exposure method	Conventional method	Long film replaced in dark room. Entire lower extremity area exposed simultaneously.
	Slot radiography	No film replacement necessary. Exposure takes place while system moves.
Image processing	Conventional method	Approx. 15 minutes required to develop images after exposure.
	Slot radiography	Approx. 2 minutes required for image processing (for 4-way exposure).
Dose	Conventional method	220 (mGy)
	Slot radiography	96.1 (mGy)
Examination time	Conventional method	30 minutes
	Slot radiography	20 minutes

Fig. 11 Comparison of Slot Radiography and Conventional Method (F/S System)

Fig. 12 Slot Radiography Images Obtained in Lower Extremity Venography
(Early Phase, Frontal, and Lateral Images)

8. Points to Note in Slot Radiography

As mentioned before, slot radiography involves the execution of imaging during movement of the system. For this reason, the acquired data incorporates an element of imprecision corresponding to this movement. For example, when observing a trabecula of bone in bone radiography, it must be kept in mind that the image quality is different to that obtained with still images. In fact, when we first introduced slot radiography at our hospital, although we considered its application to imaging of the femur, we did not reach the point of using it to visualize a trabecula of bone. There are some ways, however, in which image quality can be improved, and I would like to make a report about them on some other occasion.

Although slot radiography is mainly used for imaging of the entire spine or the entire lower extremity area, in an age when CT is used for whole-body imaging in trauma cases, it is conjectured that, in consideration of the dose, it may be worth investigating the possibility of using slot radiography for whole-body bone imaging. In the future, I expect to come across reports of a diverse range of applications.

9. Summary

Here, I have described our experiences of using the slot radiography function of the SONIALVISION safire II R/F system for lower extremity venography. Despite the disadvantage of having to set the footstool in a high position in order to perform examinations, it is an extremely useful function, which allows imaging over a large range in a single operation, makes it possible to produce seamless, distortion-free images with simple operations, and offers easy operability in image processing.

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Finally, I would like to thank Mr. Arai and Mr. Karukaya of Yamamoto Shokai for presenting me with this opportunity.

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