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Tomosynthesis Applications in Thoracic Imaging —Utility in Early Diagnosis of Lung Cancer—

Takeshi Okawa, R.T.

Simantocho Taisho Shinryosho
Takeshi Okawa

1. Introduction

Shimantocho Taisho Shinryosho (Taisho Clinic) is located in the Taisho District of Shimanto town, Kochi Prefecture. Taisho District itself is situated in the middle reaches of the beautiful Shimanto River and is home to 2,501 residents (of 17,500 in Shimanto town), 46.7 % of whom are elderly (41.6 % male and 51.4 % female as of February 2022).

Fig.1 View of Taisho Clinic

Taisho Clinic has 19 beds **(Fig. 1)** and offers emergency medical services 365 days a year. In March 2021, a SONIALVISION G4 series system (Shimadzu Co.) was installed in the clinic, adding to an existing 16-slice CT scanner and ultrasound system. As well as conventional fluoroscopic examinations, the SONIALVISION G4 series system can perform tomosynthesis (digital tomography), slot radiography (long view radiography), general radiography, and bone mineral density (BMD) measurements (of the lumbar spine and femoral neck).

As a clinic treating a high proportion of elderly patients, tomosynthesis is very useful for diagnosing disorders in the thoracic region as well as orthopedics because it offers a more accurate view of pathological conditions than general radiography and can pinpoint sites for examination at radiation doses one-third to one-tenth that of CT[1), 2), 3)].

In recent years, The Japan Ministry of Health, Labour and Welfare, The Japan Association of Radiological Technologists, the Nuclear Safety Technology Center (NUSTEC), and various medical institutions have pursued various initiatives to reduce radiation exposure among health care workers and patients amidst a growing interest in reducing radiation exposure levels. At Taisho Clinic, we also place the utmost priority on reducing the exposure of patients and medical personnel to radiation. We are using the general radiography and tomosynthesis functions of the SONIALVISION G4 series system effectively to perform imaging with as little positioning support as possible, so that radiation exposure to medical personnel who may need to reposition elderly patients during examinations can be minimized. Reducing the number of positional changes and minimizing uncomfortable positioning of the extremities have also made examinations less burdensome and more comfortable for patients. In some cases, we skip general radiography and perform tomosynthesis when examining the lungs and bone fractures in various sites. Tomosynthesis is also quick and causes less pain to elderly patients and is effective for diagnosis.

2. Using Tomosynthesis in the Thoracic Region

Between March 2021 and the end of March 2022, Taisho Clinic performed a total of 115 tomosynthesis imaging procedures, of which 40 were in the thoracic region.

In order to verify whether tomosynthesis (TOMOS) can be used for clinical evaluation in the thoracic region at our clinic, patients first underwent plain chest radiography (digital chest radiography), after which tomosynthesis was used to evaluate cases with suspicious findings.

In this article, we compare digital chest radiography, chest CT, and chest tomosynthesis for early diagnosis of lung cancer and other thoracic conditions and report on the clinical usefulness of each imaging technique in the thoracic region (ultrasound and digital radiography were compared for hairline rib fractures).

Between March 2021 and the end of March 2022, Taisho Clinic used tomosynthesis to image the thoracic region in 40 patients comprised of 14 males and 26 females aged between 28 and 96 years (mean age: 76.5 years).

Digital chest radiographs, tomosynthesis images, CT images, and ultrasound images were evaluated on a PACS workstation. Images were examined for

10 findings: (1) ground-glass opacities, (2) infiltrative shadows, (3) nodular shadows, (4) changes in pulmonary vascular shadows, (5) bronchiole wall thickening, (6) interlobular septa thickening, (7) reversed halo signs, (8) rib fractures (including the sternum and costal cartilage), (9) honeycomb lung, and (10) pleural thickening **(Table 2)**.

Table 1 Clinical Data on Tomosynthesis in the Thoracic Region (No. of Cases)

Bronchitis, asthma	4
Pneumonia (including acute and obsolete)	6
Pleuritis	1
Metastatic lung cancer (esophageal cancer)	1
Chronic heart failure	2
Thoracic empyema	1
COPD	6
Rib fracture	8
Costal cartilage fracture	1
Sternum fracture	1
Tortuosity of the thoracic aorta	1
Lung cancer (stage IA2)	1
Esophageal hiatal hernia	2
Pneumothorax	1
Heart valve disease	1
Benign lung tumor	19
Other, no findings	7

Table 2 Image Evaluation

(1)	Ground-glass opacity
(2)	Infiltrative shadow
(3)	Nodular shadow
(4)	Changes in pulmonary vascular shadows
(5)	Bronchiole wall thickening
(6)	Interlobular septa thickening
(7)	Reversed halo signs
(8)	Rib fracture (including the sternum and costal cartilage)
(9)	Honeycomb lung
(10)	Pleural thickening

3. Results of Image Evaluation

Table 3 Results of Image Evaluation (No. of Cases with Confirmed Visualization)

	Image Evaluation	DR	TOMOS	CT
(1)	Ground-glass opacity	2	4	4
(2)	Infiltrative shadow	2	4	4
(3)	Nodular shadow	3	19	19
(4)	Changes in pulmonary vascular shadows	0	4	8
(5)	Bronchiole wall thickening	0	4	6
(6)	Interlobular septa thickening	0	2	7
(7)	Reversed halo signs	0	3	3
(8)	Rib fracture (including the sternum and costal cartilage)	4	8	9 by ultrasound (no CT evaluation)
(9)	Honeycomb lung	2	5	6
(10)	Pleural thickening	6	12	12

3.1 Ground-Glass Opacity

Ground-glass opacity is often seen in cases of interstitial pneumonitis. Pathologically, ground-glass opacity is defined as a pale shadow due to exudate or secretions in some areas of the alveoli or interstitium while air is retained in the alveoli. Tomosynthesis is less accurate than CT at the margins of the lungs that overlap the ribs, but accuracy can be increased by adjusting the viewing angle of the reconstructed image or by reducing the slice pitch.

Ground-glass opacities are non-specific findings seen with both parenchymal (alveolar epithelial cell and alveolar space) lesions and interstitial lesions, and tomosynthesis is far superior to digital chest radiography in detecting ground-glass opacities in the early stages of COVID-19 and other pathologies[4].

3.2 Infiltrative Shadow

Infiltrative shadow (consolidation) is principally seen in cases of parenchymal pneumonia. Healthy alveoli are full of air and appear black in radiographs while an infiltrative shadow appears pure white and indicates a problem in the lung parenchyma such as displacement of air from alveoli by exudate, secretions, or sputum. Tomosynthesis and CT are more comparable in their ability to visualize infiltrative shadows than ground-glass opacities, and tomosynthesis is far superior to digital chest radiography in detecting infiltrative shadow lesions. Tomosynthesis in the thoracic region should also be capable of visualizing small ground-glass opacities and small infiltrative shadows that cannot be visualized by digital chest radiography.

3.3 Nodular Shadow

Nodular shadows are often identified when digital chest radiography or CT is performed in asymptomatic patients during medical checkups or for coughs or similar symptoms. The identification of nodular shadows, ground-glass opacities, and band-like opacities is extremely important for the imaging-based diagnosis of lung cancer. However, benign lesions such as post-inflammatory changes and intrapulmonary lymph nodes also form nodular shadows.

Compared to digital chest radiography, tomosynthesis is reported to be 37 % more sensitive at detecting pulmonary nodules 10 mm or larger in size[2].

Digital chest radiography often misses nodules that are around 10 mm in size when they overlap bony structures in the thoracic region, overlap blood vessels, are located behind the diaphragm or around the heart, or when there is ossification of costal cartilage. Tomosynthesis offers clear visualization of nodules 10 mm and smaller regardless of any overlap with other structures.

At Taisho Clinic, we have seen similar results from CT and tomosynthesis in visualizing nodular shadows, with 19 cases confirmed by CT, 19 by tomosynthesis, and 3 by digital chest radiography **(Table 3)**. Digital chest radiography is clearly of limited use in visualizing small nodular shadows, while tomosynthesis provides clear visualization of granular shadows, mass shadows, and nodular shadows 3 to 5 mm in size (**Fig. 2 to 7**, all from the same patient).

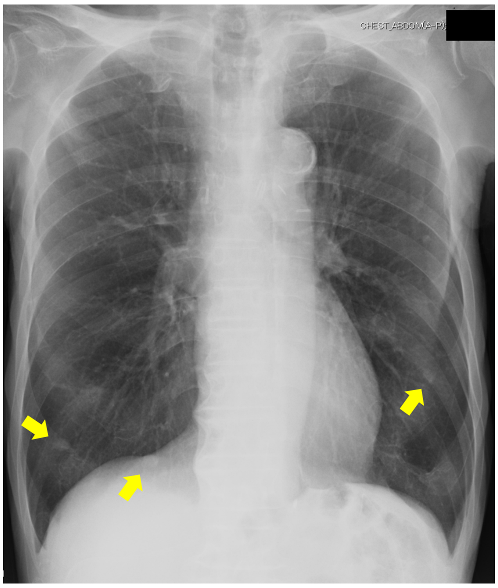

Fig.2 80-year-old male with lung metastases after esophageal cancer surgery. Nodules 9 mm and smaller are difficult to distinguish on digital chest radiographs.

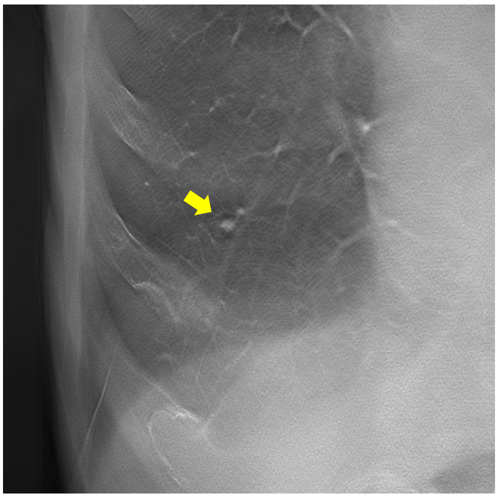

Fig.3 Esophageal cancer with lung metastasis. TOMOS image showing 3-mm nodule in right inferior lobe.

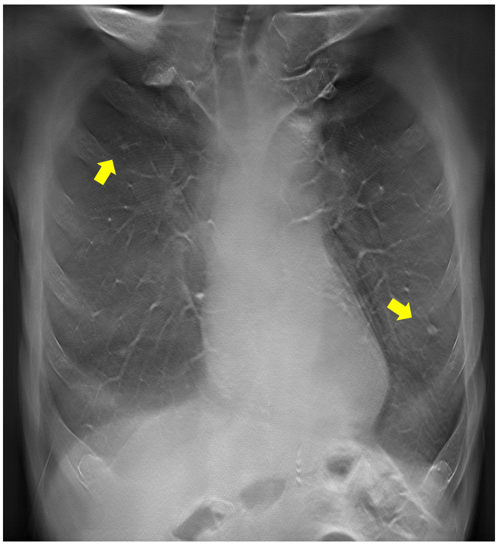

Fig.4 Esophageal cancer with lung metastasis. TOMOS image showing 4-mm nodule in right superior lobe and 5-mm nodule in left inferior lobe.

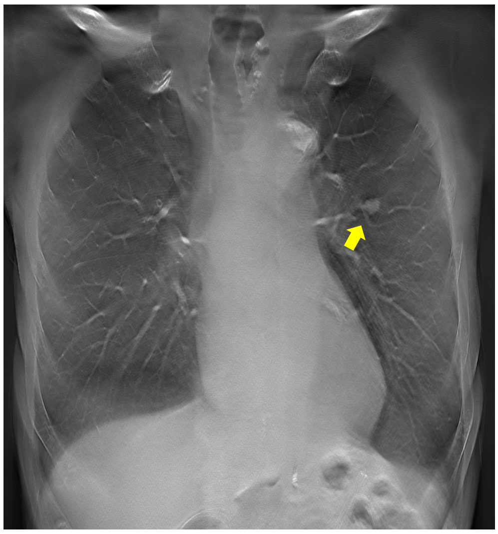

Fig.5 Esophageal cancer with lung metastasis. TOMOS image showing 6-mm nodule in left superior lobe.

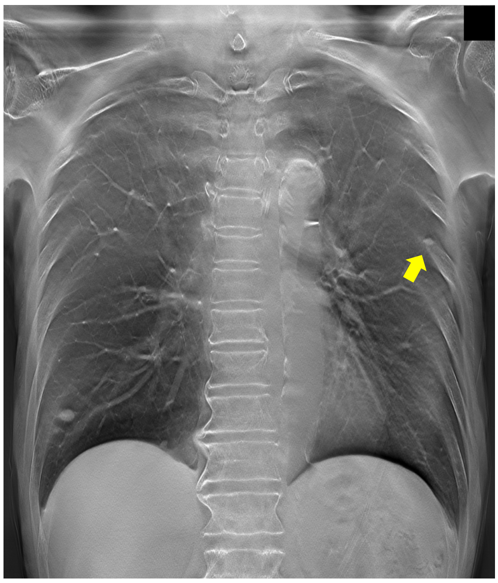

Fig.6 Esophageal cancer with lung metastasis. TOMOS image showing 9 and 4-mm nodules in right inferior lobe and 4-mm nodule in left superior lobe.

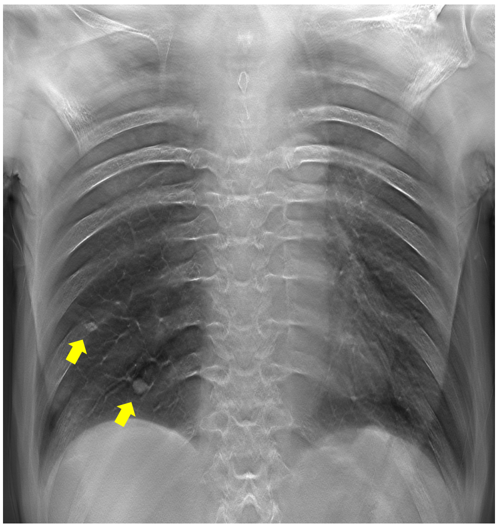

Fig.7 Esophageal cancer with lung metastasis. TOMOS image showing 5 and 6-mm nodules in right inferior lobe.

Although CT has overtaken digital chest radiography as the principal imaging modality of choice for imaging-based diagnosis of shadows in early-stage lung cancer, CT also comes with issues such as increased imaging times and increased radiation exposure. When we used tomosynthesis for diagnostic imaging of early-stage lung cancer, breath-holding times were reduced due to 2.5-second high-speed scanning times, and image data reconstruction was quicker than CT. Tomosynthesis is also reported to use one-third to one-tenth the radiation dose of CT (dose varies by CT scan conditions)[1), 2), 3), 4)]. Replacing digital chest radiography with thoracic tomosynthesis for screening applications should help the early diagnosis and treatment of lung cancer and save numerous lives **(Fig. 8, 9)**.

3.4 Changes in Pulmonary Vascular Shadows

Pulmonary vascular shadows are changed by pulmonary lesions. These changes are identified by close examination of images for the thickness and number of pulmonary vessels. Thinning of a pulmonary vessel suggests a condition that causes reduced pulmonary blood flow, and attenuation of a pulmonary artery shadow is the main thoracic finding of chronic pulmonary arterial embolism. Because tomosynthesis provides clear visualization of the pulmonary vasculature regardless of overlapping blood vessels above or below the vessel of interest, abnormal pulmonary vascular shadows and vascular changes caused by air trapping and hyperinflation of the lungs are visible in tomosynthesis images, and since tomosynthesis images can be interpreted using the same principles as digital chest radiographs and CT images, tomosynthesis offers a more convenient method for evaluating pathophysiology based on lung volume, lung permeability, and pulmonary vascular shadows.

3.5 Bronchiole Wall Thickening

The main airways (bronchi) of the lungs branch off into smaller and smaller passageways. The bronchioles

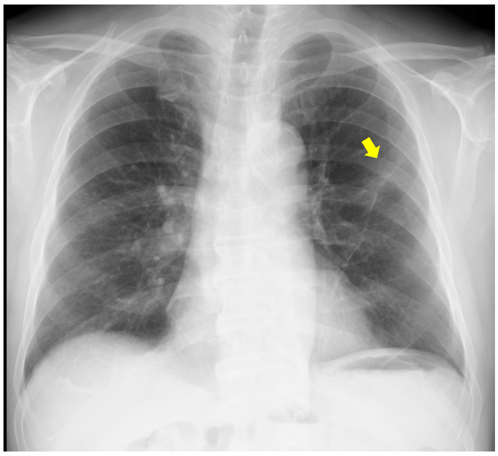

Fig.8 Digital Chest Radiograph Showing trabecular shadow in Left Superior Lobe in Patient with Lung Cancer

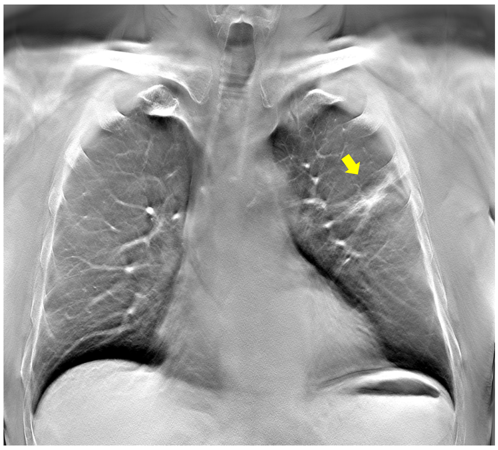

Fig.9 TOMOS Image Showing Stage I A2 Lung Cancer in Left Superior Lobe

begin where these bronchial airways narrow to an inner diameter of around 1 mm or smaller and end just before the respiratory bronchioles that lead to alveolar structures. Bronchioles also lack the supporting cartilage skeletons found in the bronchi.
High-resolution CT is used to evaluate bronchial asthma and bronchiolitis, but we have also been able to evaluate bronchial wall thickening with tomosynthesis. Tomosynthesis can also visualize the tree-in-bud pattern of centrilobular nodules.

3.6 Interlobular Septa Thickening

Thickening of the interlobular septa is also a common finding. In digital chest radiography, this thickening is visualized as Kerley lines. Causes of interlobular septa thickening include edema in the interstitium caused by pulmonary edema and cancerous lymphangiopathy and fibrosis in the interstitium caused by interstitial pneumonitis. Although inferior to high-resolution CT (HRCT), interlobular septa thickening has also been visualized by tomosynthesis.

3.7 Reversed Halo Sign

The reversed halo sign was once considered unique to organizing pneumonia (OP), but this association has become less definitive as the reverse halo sign was also observed in association with many other conditions including infectious diseases and pulmonary embolism. We confirmed the reversed halo sign in both lungs by tomosynthesis as a finding of COPD **(Fig. 10, 11)**.

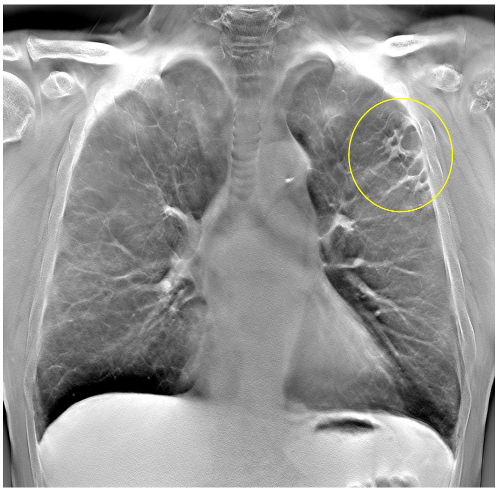

Fig.10 Reversed Halo Sign in Left Superior Lobe

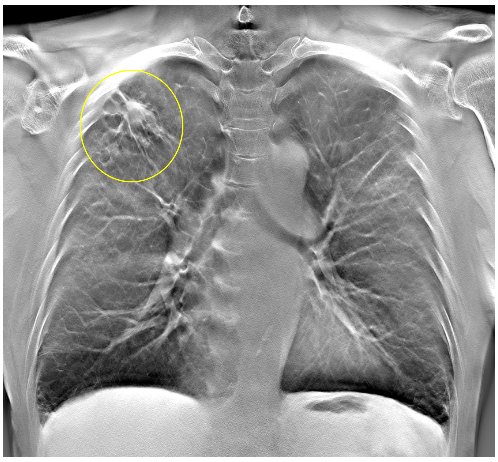

Fig.11 Reversed Halo Sign in Right Superior Lobe (Same Patient as **Fig. 10**)

3.8 Rib Fracture (Including Sternum and Costal Cartilage)

Physicians sometimes have difficulty diagnosing fragility microfractures in patients with osteoporosis, even when images are acquired by radiological technologists with extensive experience in digital radiography. Tomosynthesis has recently become a very useful diagnostic tool in orthopedic medicine and is extremely good at detecting fractures in the thoracic region otherwise identified as suspected fractures by digital radiography. Comparing suspected fracture cases in the thoracic region by imaging technique, of 9 cases confirmed to have a fracture at our clinic, 4 were apparent on digital radiography, 8 on tomosynthesis, and 9 on ultrasound. This favorable diagnostic performance of tomosynthesis may be because the tomographic plane was adjusted parallel to the fractured rib, thereby improving the visibility of fractures. These outcomes also show how the ability to mostly eliminate bone and other overlapping thoracic structures allows tomosynthesis to visualize very small fracture lines **(Fig. 12, 13)**.

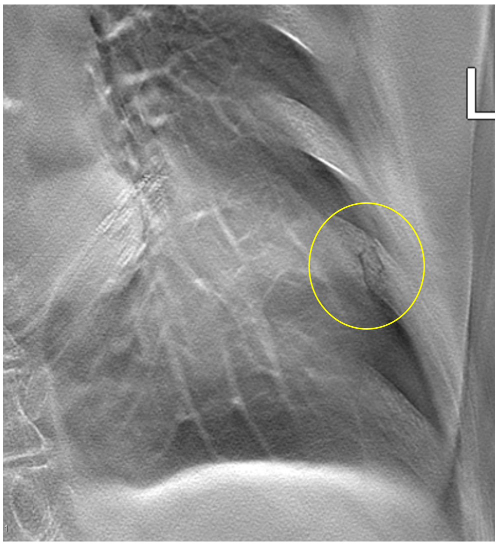

Fig.12 Obvious Rib Fracture Due to Minimal Interference from Overlapping Ribs and Other Anatomical Structures

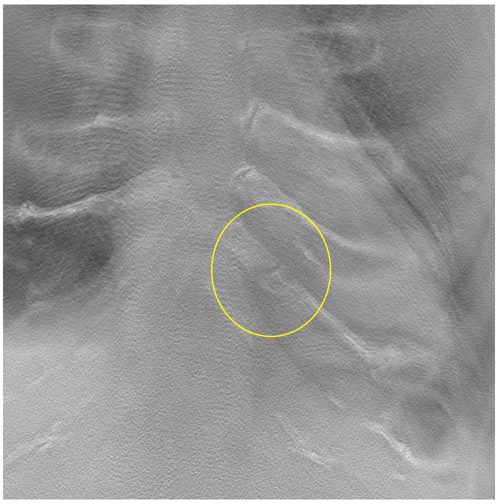

Fig.13 Costal Cartilage Fracture

3.9 Honeycomb Lung

Honeycomb lung is seen in cases of interstitial pneumonitis and appears as a mesh-like shadow on CT. Honeycomb lung is defined as clustered, air-filled cysts typically 3 to 10 mm in diameter, usually subpleural and with clearly defined walls. Honeycomb lung forms from a combination of collapsed alveoli and enlargement of alveolar ducts and alveolar lumen, indicates the presence of fibrotic changes, and can also be evaluated using tomosynthesis.

3.10 Pleural Thickening

Pleural thickening is sometimes revealed by digital chest radiography examinations performed during medical checkups. Although most instances are not pathogenic, pleural thickening is also commonly associated with health problems linked to asbestos inhalation in carpenters, plumbers, house wreckers, and auto mechanics and cannot be ignored. When inhaled, asbestos fibers become deposited in alveoli just below the pleura where they irritate the pleura and cause pleural thickening. This pleural thickening is localized and formed of pleural plaques, which often

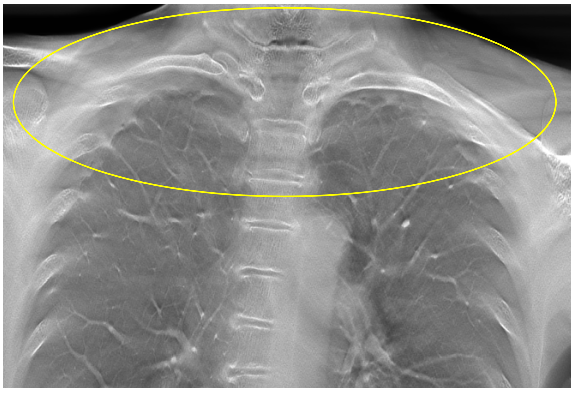

Fig.14 Well-Visualized Pleural Thickening in the Lung Apex

include calcifications on imaging. Pleural thickening is also a very common complication of malignancies such as pleural mesothelioma and lung cancer, and can also be caused by tuberculosis in the apex of the lung. Our experience shows that tomosynthesis detects pleural thickening at a higher rate than digital chest radiography, and an equivalent rate to CT **(Fig. 14)**.

4. Summarizing the Advantages of Tomosynthesis

- Tomosynthesis performs similarly to CT and is superior and more accurate at detecting lesions in the thoracic region compared to digital chest radiography.
  Although digital chest radiography is used to diagnose lung cancer, small pulmonary nodules are often overlooked by digital chest radiography when they overlap anatomical structures such as the bones of the thorax, the heart, and blood vessels in the mediastinum. This issue can also be exacerbated in cases when digital chest radiographs are only acquired from a single direction (frontal view) rather than two directions.
- Compared to digital chest radiography, tomosynthesis is less affected by overlapping anatomical structures and is reportedly 37 % more sensitive in detecting pulmonary nodules 10 mm or larger[1]. At Taisho Clinic, we have found tomosynthesis and CT perform equally well in providing good visualization of pulmonary nodules 10 mm or smaller.
- Alongside digital radiography, CT is also an important imaging technique for chest lesion examinations. Recent years have seen the use of low-dose mode CT in medical checkups and other applications, though exposure levels from CT remain high enough to pose an issue.
  Tomosynthesis can reduce radiation exposure significantly compared to CT, using radiation doses around one-tenth to one-third that of CT[1), 2), 3)].
- Shimadzu's proprietary technology allows tomosynthesis to be performed in high-speed 2.5-second scans and still produce clear images with no signs of movement, even in elderly patients who have difficulty holding their breath.
- Tomosynthesis can also be performed in semi-sitting and supine positions for patients who have difficulty maintaining a fully upright posture.
- Tomosynthesis can be used for imaging in the thoracic region and orthopedic applications with the patient standing or lying.
- Tomosynthesis is a quick and painless imaging technique that reduces the burden on elderly patients and patients who have difficulty changing positions, which is also effective for diagnosis.

5. Conclusion

As a medical institution that caters to a largely elderly population, we have found tomosynthesis useful for examining the whole thoracic region, including in patients with skeletal abnormalities or patients with a rounded or kyphotic spine that can make imaging or image interpretation a challenge when using digital chest radiography. Many of our elderly patients who undergo tomosynthesis are pleased with the undemanding nature of the examination, pleased the breath-holding time is shorter than CT, and pleased the examination is completed in only a few seconds.
Tomosynthesis is simple to implement, quick, generates low levels of exposure, and produces high-quality images of areas of interest that are suitable for evaluation. The effective application of tomosynthesis with a proper understanding of its utility allows examinations to be performed without unnecessary repositioning of the patient, eliminates patient discomfort and pain, and reduces unnecessary use of CT for lower radiation exposure. Tomosynthesis also incurs fewer national health insurance points and lower medical fees than CT.
Tomosynthesis is currently not widespread use for chest imaging, but we hope this article can go some way to encourage the effective use of tomosynthesis in the thoracic region. In concluding this article, I would like to thank Shimadzu Corporation for developing the SONIALVISION G4 series system and its excellent range of features. I would also like to thank my late father who died from lung cancer.

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