R/F

Using Tomosynthesis Images for Measuring Total Spine Alignment Parameters Using the SONIALVISION safire Series

− Also Using Tomosynthesis −

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1. Introduction

Tokyo Women's Medical University Hospital (1,423 beds [1,358 general beds and 65 psychiatric beds], average number of outpatients 4,200/day with 1,200 inpatients) has seven R/F rooms, of which the SONIALVISION safire series is installed in two rooms. We are blessed with having very capable examination facilities.

The SONIALVISION safire series can perform SLOT radiography and T-smart-equipped tomosynthesis. Since installing the SONIALVISION safire series in December 2012, it has been commended highly in the areas of spinal column and hip joint imaging, and been used to perform a large number of examinations. The average number of examinations performed with the SONIALVISION safire series per month is around 30 total spine SLOT radiography examinations and around 110 tomosynthesis examinations, of which around 80 are tomosynthesis examinations of the spine and hip joints. Elsewhere, we have performed 233 total spine radiography examinations using a long view cassette in general radiography rooms. In this article, we report on assessment parameters used with total spine SLOT radiography (frontal and lateral) and on pelvic sagittal parameter measurements with tomosynthesis, based on experiences at our hospital.

2. Disease Targets and Objectives of Total Spine Radiography and Tomosynthesis

Some of the target diseases for total spine radiography are scoliosis, osteoporosis, hip-joint diseases, and hip-spine syndrome. Scoliosis is a condition where the spinal column deviates from its correct alignment that is caused by a variety of diseases[1)]. Scoliosis affects all ages of people, from the elderly to newborn infants, all of whom are subjects for radiography. Considering hip-joint diseases and hip-spine syndrome, it is thought that hip-joint diseases may become a cause of lumbar diseases, and lumbar diseases may become a cause of hip-joint diseases, with each disease affecting the other. Therefore, we perform total spine radiography that includes imaging of both the spine and the hip joints **(Fig. 1)**.

Total spine radiography is an essential means of assessing the shape of the spinal column. The objective of total spine radiography is to determine a treatment strategy and predict the progression of the disease.

Typical Spinal Deformity Diseases by Category	
• Idiopathic	• Bone infection
• Neuromyogenic	• Metabolic disease
• Congenital	• Synsacrum disease-related
• Neurofibromatosis	• Tumor
• Mesenchymal abnormality	• Postural
• Rheumatic disease	• Hip-joint contracture
• Trauma	• Lower limb length difference
• Spine contracture	• Kyphosis
• Osteochondrodysplasia	• Lordosis

Fig. 1

3. Total Spine SLOT Radiography: Body Positioning, Field of View, and Exposure Conditions

3.1 Body Positioning

At our hospital, total spine radiography is performed in the following body views: standing front, standing lateral, prone front, supine lateral, seated front, seated lateral, and stress-loaded. Seated radiography is performed in patients with severe cerebral palsy, a paralytic disease of the lower extremities, or patients whose spinal deformity has become so severe they are unable to stand and must use a wheelchair, such as patients with Duchenne muscular dystrophy. Stress radiography is used to find the flexibility of a curved spine and determine the type of deformation or range of immobilization to be implemented during surgery. This includes traction radiography where the patient spine is pulled in the cranocaudal direction, as well as bending test radiography (push-prone or fulcrum bending) where radiography is performed with the patient in a prone position while adjusting the patient's position to correct the main curve in the spine.

As for standard radiography body positions, the Scoliosis Research Society (SRS) recommends that for frontal images the subject stands naturally with both arms by their side, and for lateral images the subject stands naturally with feet slightly apart, hands lightly clenched, and both elbows bent with hands touching the superior fovea above the clavicle (clavicle position). We take patient safety very seriously at our hospital, and radiography in the clavicle position is performed using a supporting bar set at a height that, when held by the patient, gives a mild but natural extension of the elbows away from the body. Furthermore, since supporting patients during radiography is difficult because of the design of the SONIALVISION safire series and radiography can take around five seconds, SLOT radiography is only performed in adult and elderly patients, and examination of patients below adult ages, seated radiography and stress radiography are implemented with a long view cassette in the general radiography room **(Fig. 2, Fig. 3)**.

Fig. 2 Total Spine Radiography Front and Lateral Body Positions
(a) Front **(b)** Clavicle position
(c) Clavicle position with support bar

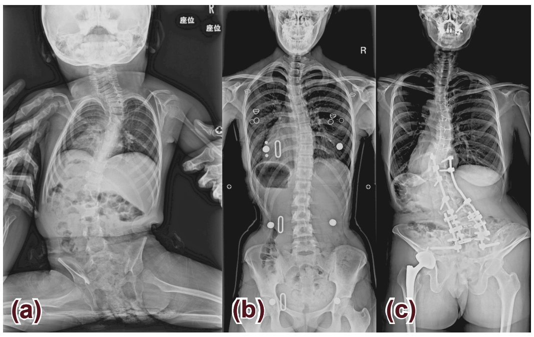


Fig. 3 Spinal Deformities and Radiography System Use by Age Group
(a) 3-year-old, seated, long view image plate (IP), supported from the sides by two technologists
(b) 15-year-old, idiopathic scoliosis, long view IP
(c) 38-year-old, SLOT radiography

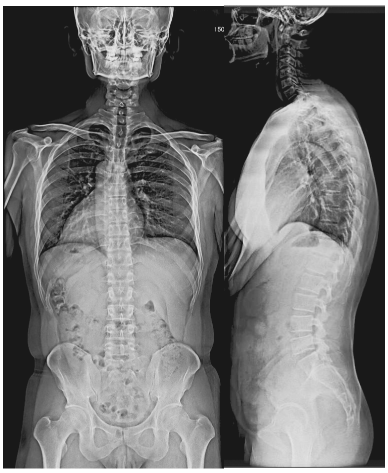


Fig. 4 Field of View of Total Spine Radiography Performed at This Hospital

3.2 Field of View

The field of view of total spine frontal radiography is large enough to include the area from the lower edges of the eye sockets to the lower edge of the pubic bone while including the femur heads on the sides. The field of view of total spine lateral radiography is large enough to include the area from the protrusion at the back of the skull to the lower edge of the pubic bone and the femur heads on the sides **(Fig. 4)**.

3.3 Exposure Conditions

To reduce patient exposure as much as possible, while the source-to-image distance (SID) of the long view cassette in plain radiography is 200 cm, we use an SID of 150 cm at this hospital[2].

Frontal radiography dependent on body thickness **(Fig. 5 (a))**.
S size: 85 kV, 400 mA, 4.5 ms
M size: 85 kV, 400 mA, 6.3 ms
L size: 95 kV, 400 mA, 6.3 ms
Lateral radiography also dependent on body thickness **(Fig. 5 (b))**.
S size: 120 kV, 400 mA, 4.5 ms
M size: 125 kV, 500 mA, 6.3 ms
L size: 135 kV, 500 mA, 8 ms

Body thickness	S	M	L
Tube voltage	85 kV	85 kV	95 kV
Tube current	400 mA	400 mA	400 mA
Exposure time	HS:4.5msec	HS:6.3msec	HS:6.3msec

Fig. 5 (a) Total Spine Frontal Exposure Conditions

Body thickness	S	M	L
Tube voltage	120 kV	125 kV	135 kV
Tube current	400 mA	400 mA	500 mA
Exposure time	HS:5msec	HS:6.3msec	HS:8msec

Fig. 5 (b) Total Spine Lateral Exposure Conditions

4. Assessment Parameters for Total Spine SLOT Frontal Images [3) 4) 5)]

To assess total spine SLOT frontal images, vertebral bodies are numbered and the following parameters are confirmed: Cobb angle, C7 plumb line-center sacral vertical line (C7-CSVL), rib-vertebra angle difference (RVAD), Risser sign, Y-cartilage (triradiate cartilage), rotation of apical vertebral body (Nash & Moe classification), vertebral body abnormalities, presence/absence of transitional vertebra, and number of ribs. We look at not only the chest, but also for hip-joint diseases and at the waistline. Consequently, frontal images must allow us to observe the skin surface and cartilage in addition to vertebral bodies **(Fig. 6)**.

Total Spine Frontal Image Assessment Parameters

- Cobb angle
- C7-CSVL
- Apical vertebra number
- Presence of malformed/deformed vertebra
- Rib-vertebra angle/rib fusion/absent rib/rib gap
- Shoulder balance, waist balance
- Risser sign/Y-cartilage (triradiate cartilage) still open
- Rotation of apical vertebral body (Nash & Moe classification)
- Pelvic incidence angle

Fig. 6

1) Cobb angle: When lines are drawn parallel to the top edge of the upper end vertebra and the bottom edge of the lower end vertebra, the Cobb angle is the angle between the lines drawn perpendicular to these two lines. In cases of adult scoliosis, a deformity with an angle below 30° is not considered a curvature of the spine **(Fig. 7)**.
2) C7 plumb line-center sacral vertical line (C7-CSVL): The perpendicular distance between a line drawn vertically through the center of the C7 vertebral body and a line drawn vertically up through the mid-point of the sacrum **(Fig. 8)**.
3) Rib-vertebra angle difference (RVAD): The difference in the rib-vertebra angle on the left and right sides is assessed and related to the progression of scoliosis. No overlap between the rib head and the apical vertebra is termed Phase 1, and when the rib head overlaps with the apical vertebral body this is termed Phase 2 and indicates progression to scoliosis **(Fig. 9)**.

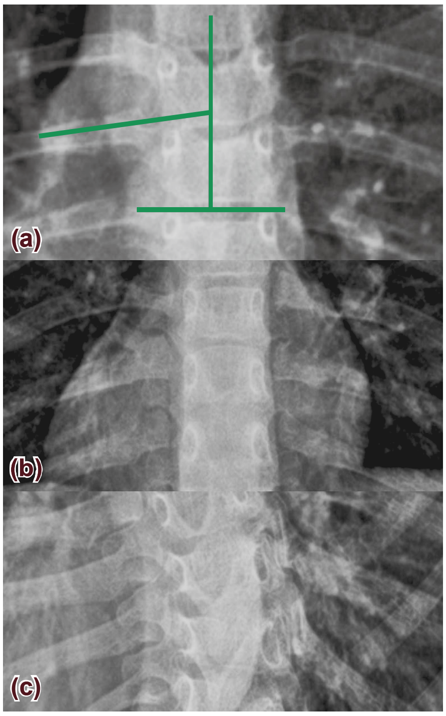


Fig. 9 Rib-Vertebra Angle

(a) The angle formed by a perpendicular line that passes through the middle of the upper or lower edge of the apical vertebra and the line that passes through the mid-points of the rib head and the rib neck.

(b) Rib head and vertebral body do not overlap in early onset of scoliosis (Phase 1)

(c) Rib head and vertebral body do overlap after progression to scoliosis (Phase 2)

4) Risser sign: Bone maturity is also a relevant factor in scoliosis progression, so bone maturity is assessed. The iliac crest is divided into four equal parts and the progression of ossification of the ossification center is determined. A complete absence of the ossification center is Risser's grade 0. As the ossification center forms across the iliac crest, the point when ossification is complete and there is fusion of the iliac crest apophysis is Risser's grade 5. At grade 0, assessment is made by Y-cartilage (triradiate cartilage) fusion. The Y-cartilage is said to close at around 12 years in girls, and 14 years in boys **(Fig. 10, Fig. 11)**.

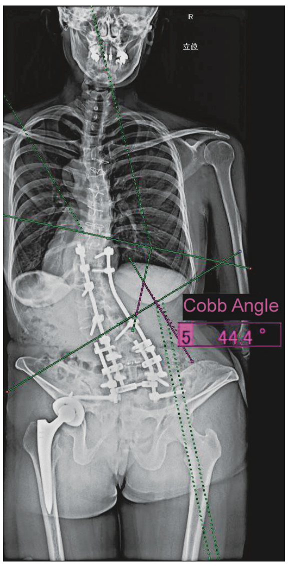


Fig. 7 Cobb Angle
When lines are drawn parallel to the top edge of the upper end vertebra and the bottom edge of the lower end vertebra, the angle between the lines drawn perpendicular to these two lines

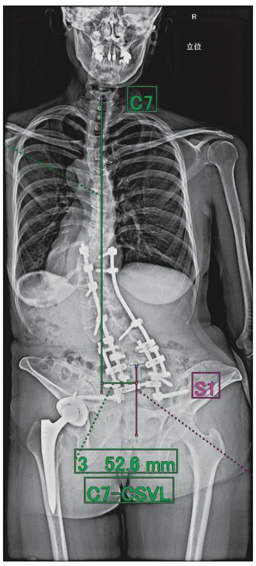


Fig. 8 C7-CSVL
Distance between a line drawn vertically through the center of the C7 vertebral body and a line drawn vertically up through the mid-point of the sacrum

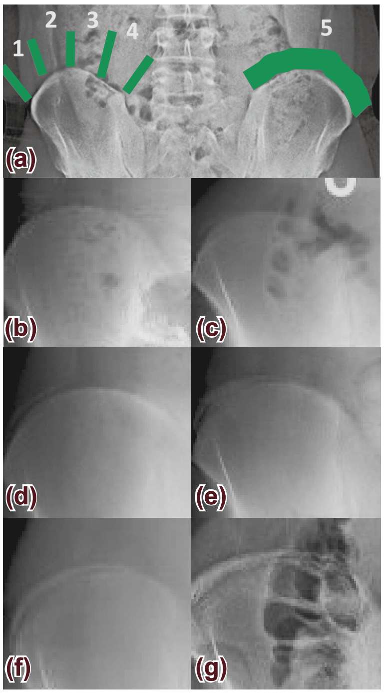


Fig. 10 Risser Sign: Determination of Bone Maturity by Ossification Center of The Iliac Crest

- **(a)** Iliac crest is divided into four equal parts.
- **(b)** No ossification center at all is Risser's grade 0.
- **(c) to (f)** show appearance of the ossification center by quarters, according with Risser's grades 1, 2, 3 and 4.
- **(g)** Risser's grade 5 when the ossification center crosses the entire iliac crest and the iliac crest apophysis is fused.

Fig. 11 Whether the Y-Cartilage Is Still Open: Risser's Grade 0
(a) Y-cartilage is open **(b)** Y-cartilage is closed

5) Rotation of apical vertebral body: Generally, the largest vertebral body rotation occurs at the apical vertebra. Rotation is assessed according to the 5 grades (0 to 4) of the Nash & Moe classification. Congenital scoliosis occurs not only as malformation of vertebral bodies, but often as morphological abnormality of the ribs and chest. Literature has shown that measuring abnormal distances between ribs in the vicinity of the apical vertebra can be a simple way of estimating scoliosis progress even in cases when it is difficult to distinguish the constituent parts of a diseased vertebral body. Consequently, visualization of both the vertebral body and the ribs is important.

5. Assessment Parameters for Total Spine SLOT Lateral Images [3) 4) 5)]

The parameters we measure to assess total spine SLOT lateral images are the degree of kyphosis in thoracic vertebrae Th2 to Th12 and Th5 to Th12, degree of kyphosis in thoracolumbar vertebrae Th10 to L2, degree of lordosis in lumbar vertebrae Th12 to S1, and the sagittal vertical axis (SVA) as an assessment of the balance of the entire spine (global balance). Poor alignment of the spinal column in the sagittal plane has a substantial effect in terms of patient symptoms and physical impairment, where the hip joints are the main subject of assessment when measuring sagittal spino-pelvic alignment (SSPA), a measure that is based on pelvisacral measurements. Consequently, lateral images must allow us to observe from the C7 vertebra to the head of both femurs and the pubic symphysis **(Fig. 13, Fig. 14, Fig. 15)**.

1) Lumbar-lordosis (LL): The angle formed between the upper edge of the L1 vertebral body and the upper edge of the S1 vertebral body
2) Thoracic-kyphosis (TK): The angle formed between the upper edge of the Th5 vertebral body and the lower edge of the Th12 vertebral body
3) Thoraco-lumbar angle: The angle formed between the upper edge of the Th10 vertebral body and the lower edge of the L2 vertebral body
4) Sagittal vertical axis (SVA): The anteroposterior distance between a line drawn vertically through the middle of the C7 vertebral body and the upper edge of the posterior side of the S1.
5) Pelvic incidence angle: The pelvic incidence angle is the angle between the line that joins the sacral promontory and upper edge of the pubic symphysis and a vertical line. The further forward the incidence of the pelvis the smaller the angle, and the further backward the incidence of the pelvis the greater the angle.

6. Pelvic Sagittal Plane Parameters [3) 4) 5)]

Based on the concept of spino-pelvic harmony where the spinal column tries to maintain good balance in the sagittal plane by adoption of an alignment appropriate to the pelvic morphology of the individual person, pelvic sagittal plane parameters are a recommended as important factors in determining sagittal plane alignment after spine correction surgery. Based on femur heads and sacral bone, these parameters include pelvic incidence (PI) and sacral slope (SS) that are characteristic to the individual and not affected by anteroposterior incidence of the pelvis, and pelvic tilt (PT), which is related to the position of the sacrum and pelvis relative to each other. The relationship between these parameters is PI = SS + PT **(Fig. 16, Fig. 17)**.

Total Spine Lateral Image Assessment Parameters

- SVA (sagittal vertical axis)
- TK (thoracic-kyphosis)
- LL (lumbar-lordosis)
- PI (pelvic incidence)
- SS (sacral slope)
- PT (pelvic tilt)
- Thoracolumbar sagittal plane alignment
- Bone fusion assessment
- Pelvic incidence angle

Fig. 12

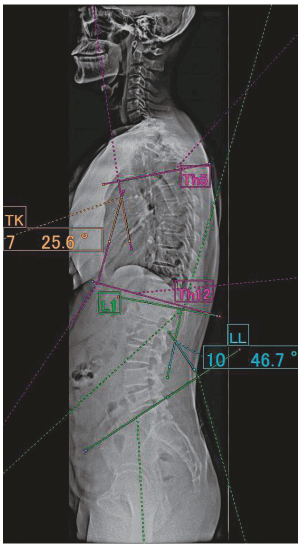


Fig. 13 TK, LL

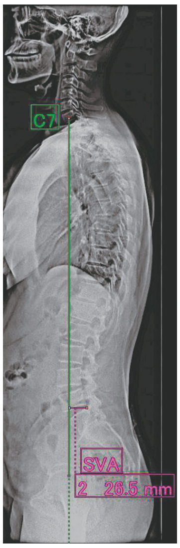


Fig. 14 SVA

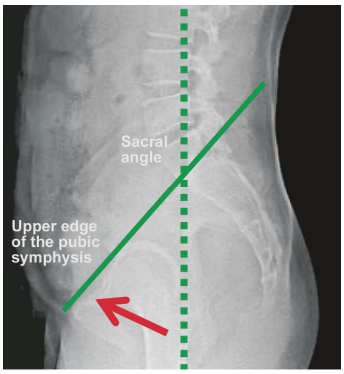


Fig. 15 Pelvic Incidence Angle

1) Pelvic incidence (PI): The angle formed between the line that joins the middle of the upper edge of the sacrum and the center of both femur heads and a line that is perpendicular to the upper edge of the sacrum. The value of this angle represents the pelvic morphology of an individual, and is not affected by anteroposterior incidence of the pelvis.
2) Sacral slope (SS): The angle formed between the upper edge of the sacrum and a horizontal line.
3) Pelvic tilt (PT): The angle formed between a vertical line and the line that joins the middle of the upper edge of the sacrum and the center of both femur heads.

   The sagittal plane deformity classification of the SRS-Schwab adult spine classification is based on the three pelvic sagittal plane parameters PI-LL, SVA, and PT.

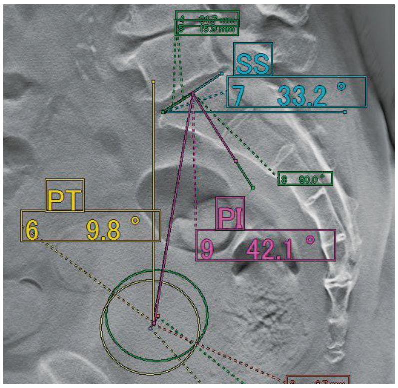


Fig. 16 Pelvic Sagittal Plane Parameters

SRS-Schwab Adult Spinal Deformity Classification
Sagittal Plane Deformity Classification

PI-LL

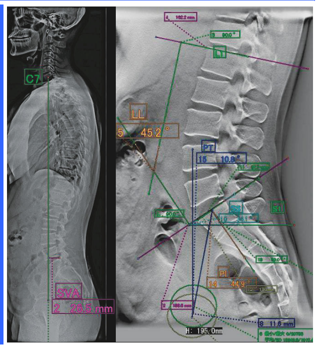
0 : < 10°
\+ : ≥ 10°, < 20°, moderate deformity
++ : ≥ 20°, marked deformity

Global Alignment

0 : SVA < 4 cm
\+ : SVA ≥ 4 cm, < 9.5 cm
++ : SVA ≥ 9.5 cm

Pelvic Tilt

0 : PT < 20°
\+ : PT ≥ 20°, < 30°
++ : PT ≥ 30°



Schwab F et al., Scoliosis Research Society-Schwab adult spinal deformity classification 2012, Spine 37
Japanese Scoliosis Society Conference, 2013, The Frontline in Scoliosis Treatment, Basic Edition
Fig. 17

7. An Assessment of Measuring Pelvic Sagittal Plane Parameters Using Standing Tomosynthesis at Our Hospital

There are many obstacles to the measurement of parameters around the pelvis from a total spine lateral view or a standing pelvis lateral view, so we assessed using tomosynthesis for the measurement of such pelvic sagittal plane parameters. We used the same body position as that used for total spine lateral radiography (clavicle position) and aligned the anteroposterior positions of the femur heads with fluoroscopy. The upper edge of the sacrum was set as the center of the image and used a 17 × 17 inch field of view. Exposure conditions were 85 kV, 400 mA, and 4.5 ms, and the measurement software used was 3D Workstation. We have access to, and were previously using, the measurement software Surgimap Spine™ that is recommended by the Scoliosis Research Society (SRS) and International Spine Study Group, but the software only captures 2D images, and imageJ is needed for measurements in order to combine images of the femur heads and sacrum, in addition to which the iliac bone overlaps target areas on the images so creating anatomical noise. All these factors make it difficult to take measurements with Surgimap Spine™. Conversely, 3D Workstation can be used to take measurements without loss of image quality from overlapping images. This is achieved by plotting and saving the position of left and right femur heads before measuring the upper edge of the sacrum. Measurements are performed by two orthopedists and two radiological technologists, with an intra-examiner intra-class correlation coefficient (ICC) of $\geq$ 0.95, and an inter-examiner ICC of $\geq$ 0.94, which demonstrates high correlation. We can also measure the upper edge of the sacrum after metal object insertion following spine surgery, and the position of both femur heads can even be ascertained in patients with artificial hip joints **(Fig. 18, Fig. 19, Fig. 20, Fig. 21)**.

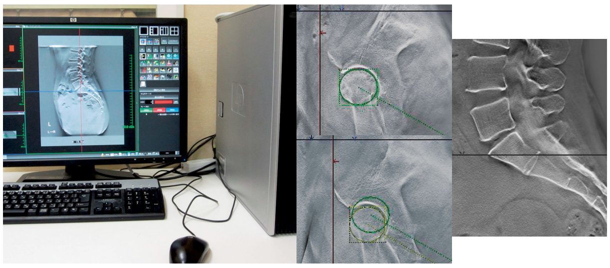
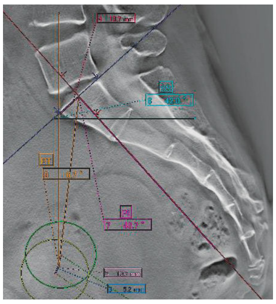


Fig. 18 Measurements Using 3D Workstation



Measurements taken without image overlaps. The upper edge of the sacrum is measured after having plotted the position of left and right femoral heads, resulting in no loss of image quality.

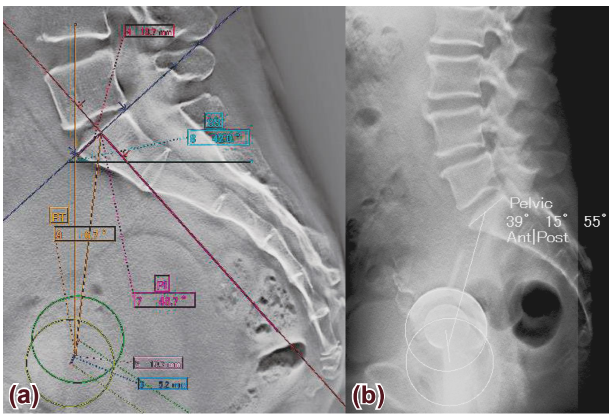


Fig. 19 Measurement Software
- **(a)** Using 3D Workstation, the upper edge of the sacrum and femur heads are clearly verifiable.
- **(b)** Using Surgimap Spine™, the iliac bone overlaps the upper edge of the sacrum, and in people with artificial hip joints the femur heads are not verifiable.

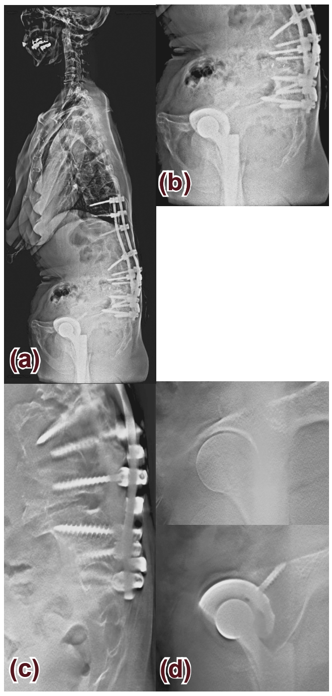


Fig. 20 Measurement of Pelvic Sagittal Plane Parameters in a 38-Year-Old
- **(a)** Total spine SLOT lateral view
- **(b)** Enlargement of the pelvic area in **(a)**, with image overlap making measurements difficult
- **(c)** Tomosynthesis making the upper edge of the sacrum more easily verifiable than with SLOT radiography
- **(d)** Both femur heads easily verifiable even with artificial hip joints

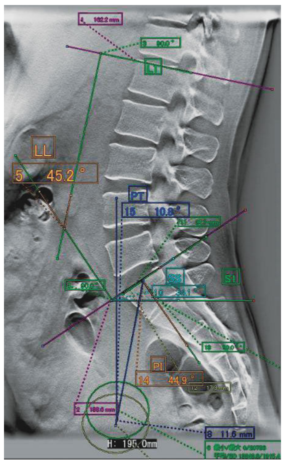


Fig. 21 Measurement of Pelvic Sagittal Plane Parameters LL, PI, PT, and SS can be measured.

8. Future Topics and Prospects

The exposure time of both SLOT radiography and tomosynthesis is long at around five seconds, and patient movement during exposure creates images that cannot be used for parameter measurement. It is also difficult to restrict patient movement during exposure, due to the structure of the system. Since the X-ray tube only moves in a single direction, there are times when radiography cannot be performed, such as of a supine lateral view.

The problem with SLOT images is the afterimages caused by direct incident radiation, which affect measurement taking and patient diagnosis. The appearance of afterimages on total spine images can be avoided by narrowing the irradiation field, but the field of view can only be narrowed so far as imaging of the pubic symphysis is essential to total spine radiography **(Fig. 22, Fig. 23, Fig. 24)**.

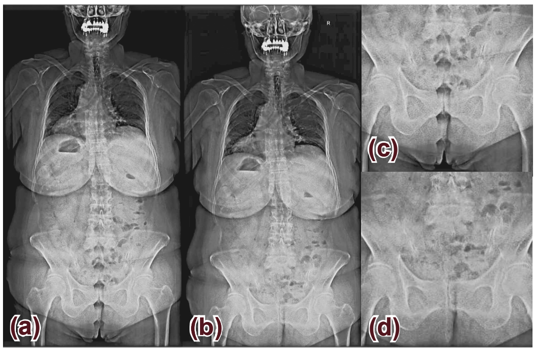


Fig. 22 Problems with Total Spine Frontal Images
- **(a)** Afterimages that resemble air occurring between L5 and the bottom of the pubic symphysis
- **(b)** Afterimages disappear when the gap in the femoral area is removed by narrowing
- **(c)** Image **(a)** enlarged
- **(d)** Image **(b)** enlarged

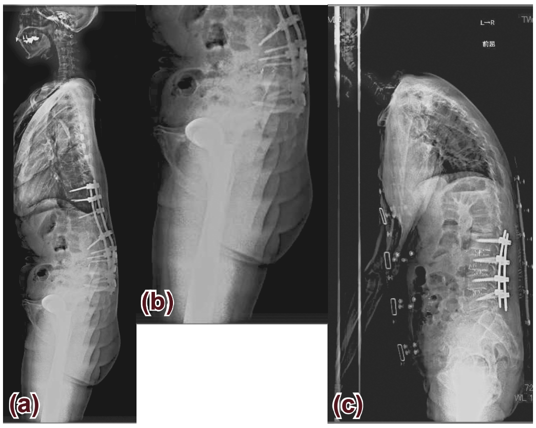


Fig. 23 Problems with Total Spine Lateral Images
- **(a)** Step-like afterimages appear around the buttocks area
- **(b)** Image **(a)** enlarged
- **(c)** Part of the table used to support the cervical spine appears in the image

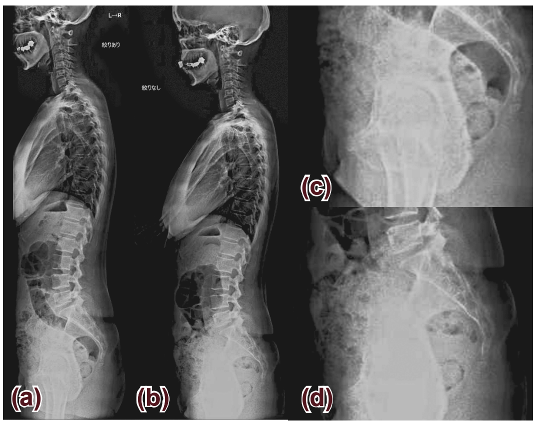


Fig. 24 Irradiation Field with Total Spine Lateral Images
- **(a)** Femur heads are visualized by narrowing the field of irradiation
- **(b)** Field of irradiation is not narrowed and femur heads are not verifiable
- **(c)** Image **(a)** enlarged
- **(d)** Image **(b)** enlarged

Looking to the future, if tomosynthesis could be adapted for long view radiography we could use it to obtain information from around the pelvis and higher thoracic vertebrae—areas that currently pose many difficulties in the measurement of parameters from a total spine lateral view. We could also acquire information on the condition of the spinal column while the patient is in a standing position. We have high expectations for the development of new ways of utilizing tomosynthesis technology.

9. Conclusion

We have reported our experiences using the SONIALVISION safire series at our hospital for the measurement of pelvic sagittal plane parameters with tomosynthesis, and for the measurement of assessment parameters from total spine SLOT images. We consider tomosynthesis to be a useful tool that allows easy measurement of pelvic sagittal plane parameters. We are always aware that the images we create will affect later decisions in treatment strategy, and it is the duty and daily pursuit of the radiological technologist to deliver accurate assessments from images that cause minimal exposure to the patient. Our aim as radiological technologists is to cooperate closely with physicians of all specialties and become ever more useful in our role.

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