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Clinical Utility of Tomosynthesis in Pediatric Orthopedics

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Abstract

In pediatric orthopedics, diagnosis using plain radiography is often challenging because of the immaturity of the epiphyses and the presence of physes. Low radiation exposure is particularly important in children. Tomosynthesis provides low-dose, high-resolution tomographic images and is therefore useful for the evaluation of epiphyseal lesions in regions where multiple bones overlap, such as the hip joint and foot. This article outlines the difficulties of plain radiographic diagnosis in pediatric bone and joint disorders and reviews the clinical utility of Tomosynthesis in pediatric orthopedics, with a focus on Perthes disease and osteochondral lesions of the talus.

1. Introduction

Tomography, which enables precise diagnostic imaging, was an important imaging modality in orthopedics before the widespread adoption of CT. However, its use with analog film was cumbersome, and tomography gradually fell out of clinical use. Advances in digital image processing technology have enabled its reintroduction into clinical practice. Low radiation exposure is particularly important in children; therefore, Tomosynthesis, which provides low-dose, high-resolution tomographic images, offers several advantages.

This article reviews the clinical utility of Tomosynthesis in pediatric orthopedics.

2. Diagnostic challenges of plain radiography in pediatric bone and joint disorders (Fig. 1)

On plain radiographs of pediatric bones and joints, the expected normal findings vary with age because the degree of epiphyseal ossification changes during growth. In the neonatal period, only the diaphysis, ossified from primary ossification centers, is visible, whereas the epiphyses remain cartilaginous and are not yet visible. With growth, ossification of the epiphyses progresses from secondary ossification centers, extending throughout each epiphysis, and the physes become distinct. Eventually, the physes undergo osseous closure, and skeletal growth is completed.

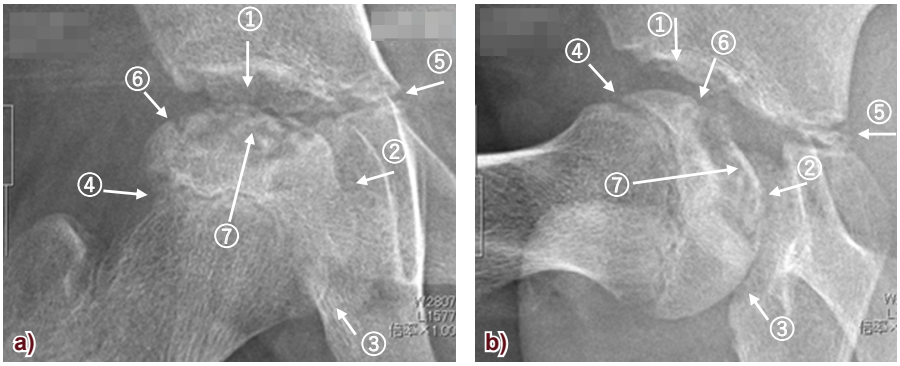

Fig. 1 Diagnostic challenges of plain radiography in the pediatric hip (Perthes disease, 11-year-old)
a) Anteroposterior (AP) image of the right hip **b)** Lateral image (Laurence view) of the right hip
① Acetabulum ② Pubis ③ Ischium ④ Proximal femoral physis ⑤ Triradiate cartilage (Y cartilage) ⑥ Resorption demarcation line of necrotic bone ⑦ Residual necrotic bone
On plain radiographs of the pediatric hip, the size of the epiphysis varies with age because the degree of epiphyseal ossification changes during growth. Superimposition with the pelvis further complicates interpretation. In the course of Perthes disease, necrotic bone is resorbed and subsequently replaced by reparative bone; however, in children with late-onset disease, necrotic bone and reparative bone coexist, making assessment more difficult.

The timing of ossification varies among bones; however, in regions composed of multiple bones (e.g., the hip joint), age-specific interpretation in diagnostic imaging becomes even more complex.
For example, the junction of the ilium, pubis, and ischium facing the acetabular floor is called the triradiate cartilage (Y cartilage). Until closure, these bones are depicted separately at this site. In addition, the femoral head also has a physis and a developing epiphysis, and it overlaps the pelvis; therefore, the presence of multiple developing bones must be carefully considered.

3. Tomosynthesis and Pediatric Orthopedic Disorders in which It Is Useful

Tomosynthesis is an imaging method that combines cone-beam CT reconstruction techniques with advanced digital image processing, enabling the acquisition of multiple consecutive tomographic slices parallel to the detector plane from a single exposure. Its main advantage is the ability to generate high-resolution images with reduced structural overlap, allowing fine trabecular architecture and other subtle structures to be clearly visualized. Imaging can be performed in flexible patient positions, and two-directional imaging can be performed by changing the position similar to plain radiography. For example, tomographic images of the hip joint can be obtained in both the anteroposterior (AP) and Lateral image (Laurence view). In addition, Tomosynthesis is a low-dose modality capable of providing high-resolution images at a lower radiation dose than CT.
Tomosynthesis is particularly useful in pediatric orthopedic conditions involving epiphyseal lesions, especially in regions with overlapping bones, such as the hip, ankle, and foot. Accurate diagnosis using clear images is essential to enable appropriate staging and to minimize the time required for assessment of healing

3.1 Perthes Disease (Pediatric Hip Disorder)

Perthes disease is one form of osteochondrosis and, although the etiology is unknown, is characterized by avascular necrosis of the femoral head epiphysis followed by a reparative process. During the phase of epiphyseal fragility associated with repair of necrotic bone, collapse and deformation of the femoral head may occur, which represents a key clinical problem. The disease predominantly affects boys around 7 years of age and typically occurs unilaterally. It may occur between 2 and 13 years of age, during which the physes are open (≤4 years: 25%, 5–8 years: 60%, ≥9 years: 15%, male-to-female ratio 8:2, unilateral-to-bilateral ratio 8:2). During its course, necrotic bone is resorbed and subsequently replaced by reparative bone. However, in children with late-onset disease (≥9 years), necrotic and reparative bone often coexist, making accurate assessment challenging.

Initial Diagnosis in Late-Onset Cases (Fig. 2)
At the initial presentation, disease progression may already be advanced, and collapse deformity of the femoral head is not uncommon. However, early diagnosis before the onset of deformity is critical for achieving favorable treatment outcomes.
Ideally, diagnosis should be established using plain radiography at the initial visit, with identification of a subchondral fracture line on the lateral image representing a key diagnostic point. However, interpretation is often challenging due to superimposition of pelvic structures and the presence of physis.
Traditionally, when Perthes disease was suspected based on plain radiographs, MRI was performed for further evaluation. However, when a subchondral fracture line can be clearly visualized using Tomosynthesis at the initial visit, a definitive diagnosis can be established.

Clinical Course in Late-Onset Child (Fig. 3)
Treatment of Perthes disease aims to prevent collapse deformity during the phase of epiphyseal fragility associated with repair of epiphyseal necrosis. Therefore, assessment of necrotic bone resorption and its replacement by reparative bone is important.
Evaluation of the three-dimensional repair process within the epiphysis is often unclear on plain radiographs because of overlapping with surrounding structures. In contrast, AP and lateral tomographic images obtained by Tomosynthesis clearly depict these reparative changes, making evaluation easier even in late-onset cases in which necrotic and reparative bone coexist.

Typical Clinical Course in the Common Age Group (Figs. 4, 5)
In children within the typical age range, the phases of necrotic bone resorption and subsequent bone repair occur in a distinct and sequential manner, in contrast to late-onset cases in which these phases overlap.

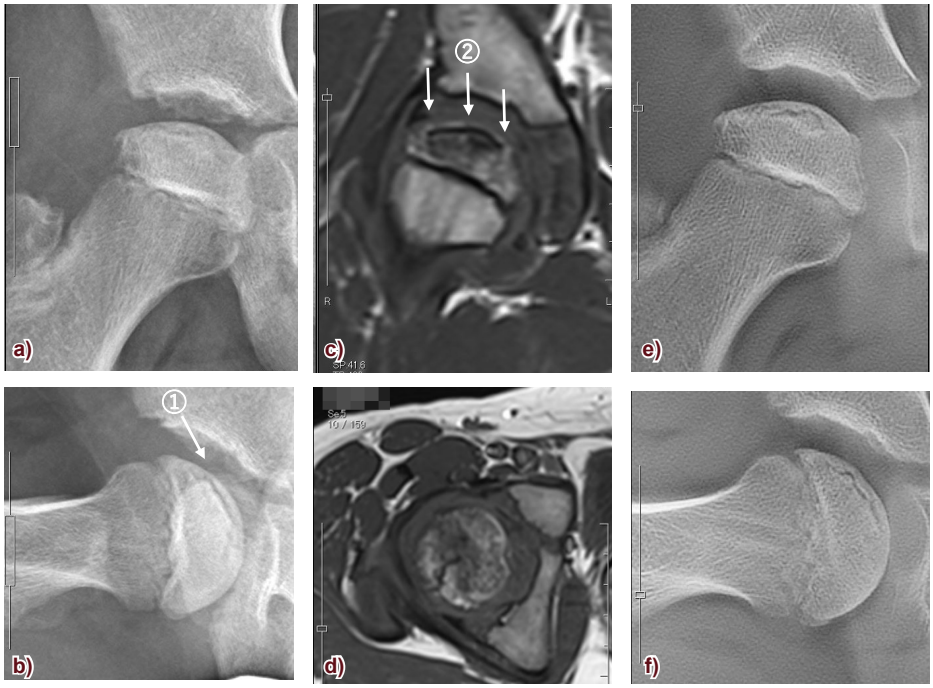

Fig. 2 Initial diagnosis (Perthes disease of the right hip in a 9-year-old child, late-onset case)
Plain radiography: **a)** AP image **b)** Lateral image (Laurence view) image
MRI: **c)** Coronal image d) Axial image
Tomosynthesis: **e)** AP image **f)** Lateral image (Laurence view)
① Subchondral fracture line (crescent sign) ② Intraepiphyseal osteonecrotic area

In Perthes disease, the stage may already be advanced at the initial visit, and collapse deformity of the femoral head is not uncommon. However, early diagnosis before the development of deformity is important, as it is associated with better treatment outcomes. Diagnosis should ideally be established using plain radiography, and identification of a subchondral fracture line on the lateral image is a key finding. Conventionally, when Perthes disease was suspected on plain radiographs, MRI was subsequently performed. However, if a subchondral fracture line can be clearly visualized using Tomosynthesis at the initial visit, a definitive diagnosis can be established. In this case, the subchondral fracture line extended over more than 50% of the epiphysis in the AP dimension, indicating severe disease (corresponding to Salter–Thompson classification type B).

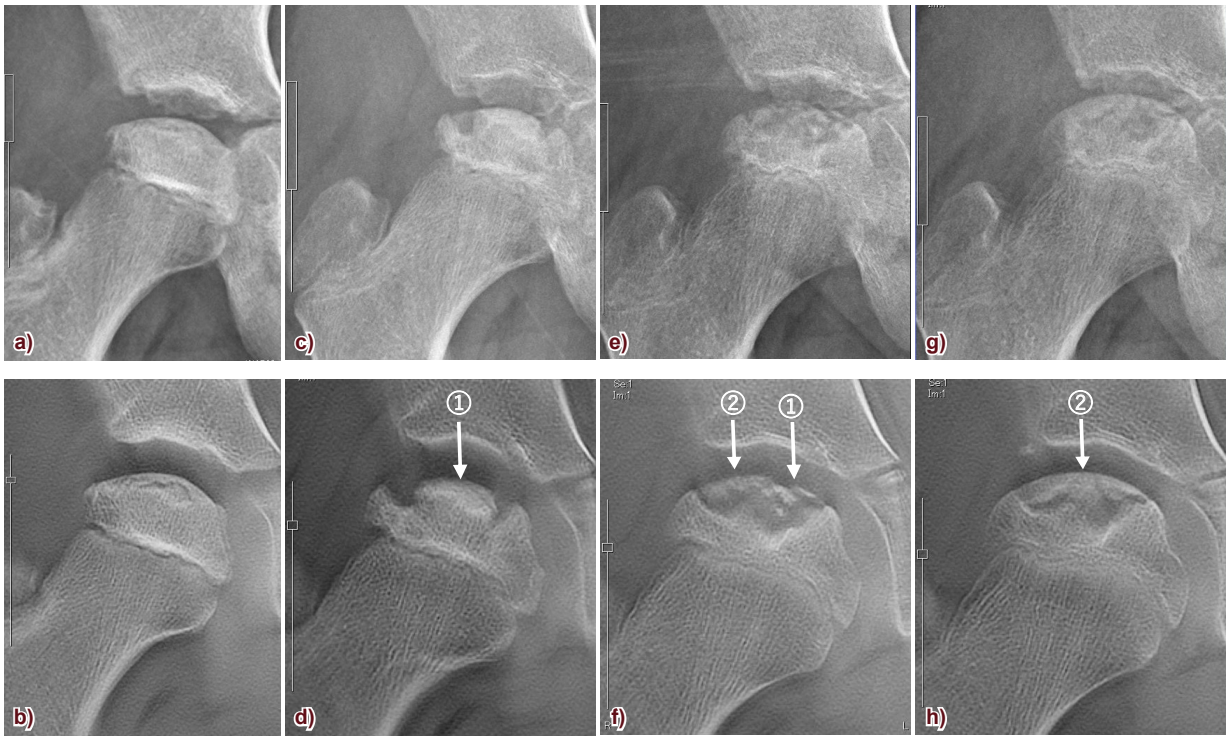

Fig. 3 Clinical course (Perthes disease of the right hip in a late-onset child)
a), **c)**, **e)**, **g)** Plain radiography **b)**, **d)**, **f)**, **h)** Tomosynthesis ① Necrotic bone, ② Reparative bone
a), **b)** At initial diagnosis (aged 9 years) **c)**, **d)** Necrotic bone resorption phase (aged 10 years)
e), **f)** Completion of necrotic bone resorption and appearance of reparative bone (aged 11 years)
g), **h)** Completion of reparative bone formation (aged 12 years)

Treatment of Perthes disease aims to prevent collapse deformity during the phase of epiphyseal fragility associated with repair following osteonecrosis of the epiphysis. Therefore, assessment of necrotic bone resorption and its replacement by reparative bone is important. Evaluation of the three-dimensional repair process within the epiphysis is often unclear on plain radiographs due to overlap with surrounding structures. In contrast, AP and lateral tomographic images obtained by Tomosynthesis clearly depict these reparative changes, making evaluation easier even in late-onset cases in which necrotic and reparative bone coexist.

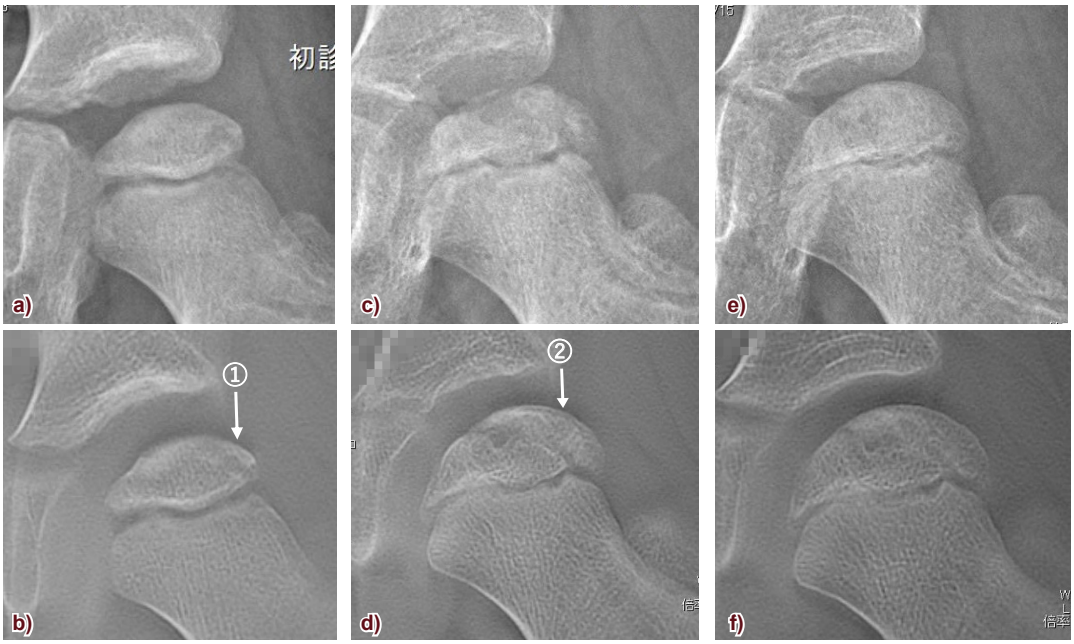

Fig. 4 Clinical course 1 (Perthes disease of the left hip in a child in the predilection age group)
a), **c)**, **e)** AP images on plain radiography **b)**, **d)**, **f)** AP images on Tomosynthesis ① Necrotic bone ② Reparative bone
a), **b)** At initial diagnosis (aged 6 years) **c)**, **d)** Appearance of reparative bone (aged 8 years)
e), **f)** Completion of reparative bone formation (aged 8 years)

In children in the predilection age group, the phases of necrotic bone resorption and subsequent bone repair occur clearly and sequentially. In contrast, in late-onset cases, these phases tend to overlap.
On AP images, necrotic bone resorption progresses rapidly, resulting in apparent disappearance of the epiphysis on radiographs. Subsequently, bone repair proceeds from the lateral side, and the appearance of reparative bone in the lateral one-third (lateral pillar) indicates the timing for resumption of weight-bearing.

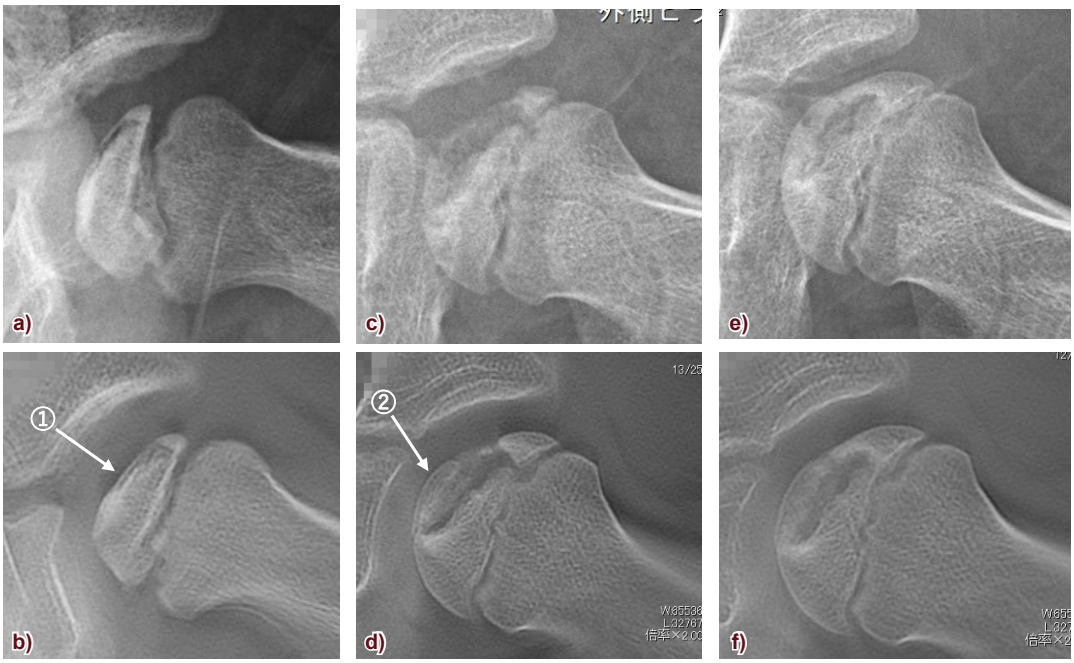

Fig. 5 Clinical course 2 (Perthes disease of the left hip in a child in the predilection age group)
a), **c)**, **e)** Lateral image (Laurence view) on plain radiography **b)**, **d)**, **f)** Lateral image (Laurence view) on Tomosynthesis
①Necrotic bone ②Reparative bone
a), **b)** At initial diagnosis (aged 6 years) **c)**, **d)** Appearance of reparative bone (aged 8 years)
e), **f)** Completion of reparative bone formation (aged 8 years)

On lateral images, the disease stage up to necrotic bone resorption is easier to determine than on AP images. Bone repair proceeds from the posterior side, however, even after the bone reparative phase has passed, an AP elongated non-reparative area tends to remain, which can be difficult to interpret. Nevertheless, if the number of Tomosynthesis sections indicates that there is no thickness in the depth direction, the finding represents only a slit-like area of non-reparative bone. Therefore, by combining this information with AP tomographic images, the timing for resuming weight-bearing can be determined as early as possible.

On the AP image, necrotic bone resorption progresses rapidly, resulting in apparent disappearance of the epiphysis on radiographs. Subsequently, bone repair proceeds from the lateral side, and resumption of weight-bearing is indicated when reparative bone appears in the lateral one-third (lateral pillar).

On lateral images, stage differentiation up to the resorption phase is often easier than on AP images. Bone repair typically progresses from posterior to anterior; however, even after the repair phase, elongated non-ossified regions may persist in the AP direction, complicating interpretation.

However, if Tomosynthesis demonstrates that such regions lack true volumetric thickness, they represent only slit-like non-ossified areas. Therefore, in combination with AP tomographic images, the timing of weight-bearing resumption can be determined as early as possible.

Severity Assessment (Figs. 6, 7)

Even in cases where a subchondral fracture line cannot be identified on conventional lateral radiographs, Tomosynthesis may allow diagnosis. When necrosis involves more than 50% of the epiphysis, the condition is classified as severe (Catterall groups 3 and 4). Subchondral fracture lines and demarcation lines of necrotic bone resorption, which may not be visible on plain radiographs, are often clearly depicted on Tomosynthesis.

In older children, the resorption and regenerative phases may overlap, resulting in a fragmented appearance that complicates interpretation. If osteonecrosis involves less than 50% of the epiphysis, the condition is considered mild (Catterall groups 1 and 2). Alternatively, disease severity can be assessed based on whether the lateral one-third of the epiphysis (lateral pillar) remains preserved, corresponding to Herring groups A and B.

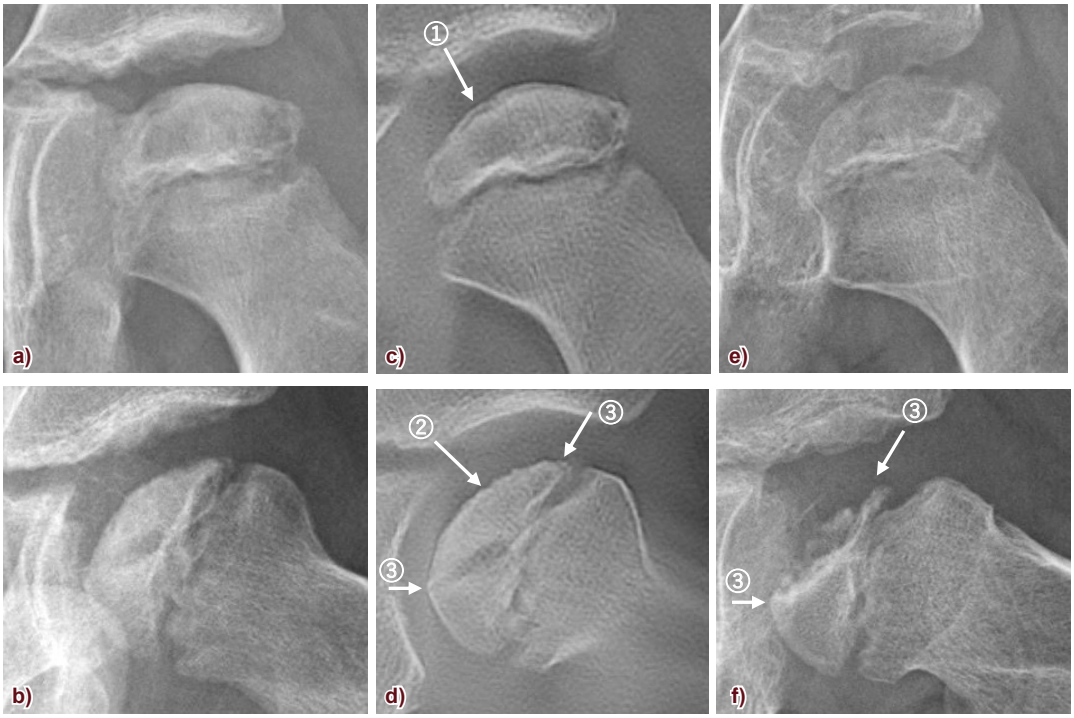

Fig. 6 Assessment of severe disease (Perthes disease of the left hip in a 6-year-old child)
Initial plain radiography: **a)** AP image **b)** Lateral image (Laurence view)
Initial Tomosynthesis: **c)** AP image **d)** Lateral image (Laurence view)
Plain radiography after 1 year (aged 7 years): **e)** AP image **f)** Lateral image (Laurence view)
① Subchondral fracture line on AP image ② Intraepiphyseal osteonecrotic area ③ Demarcation line of necrotic bone resorption

Even in cases in which a subchondral fracture line cannot be identified on the lateral image at the initial visit, Tomosynthesis may facilitate diagnosis. When osteonecrosis involves more than 50% of the epiphysis, the disease is considered severe, corresponding to Catterall groups 3 and 4. Subchondral fracture lines and demarcation lines of necrotic bone resorption, which are often not visible on plain radiographs, can be clearly depicted by Tomosynthesis. In this case, the necrotic bone was completely resorbed after 1 year, indicating that the demarcation line observed on the lateral image at the initial visit was appropriate. However, necrotic bone resorption is also unclear on the AP image, illustrating the difficulty of interpreting plain radiographs.

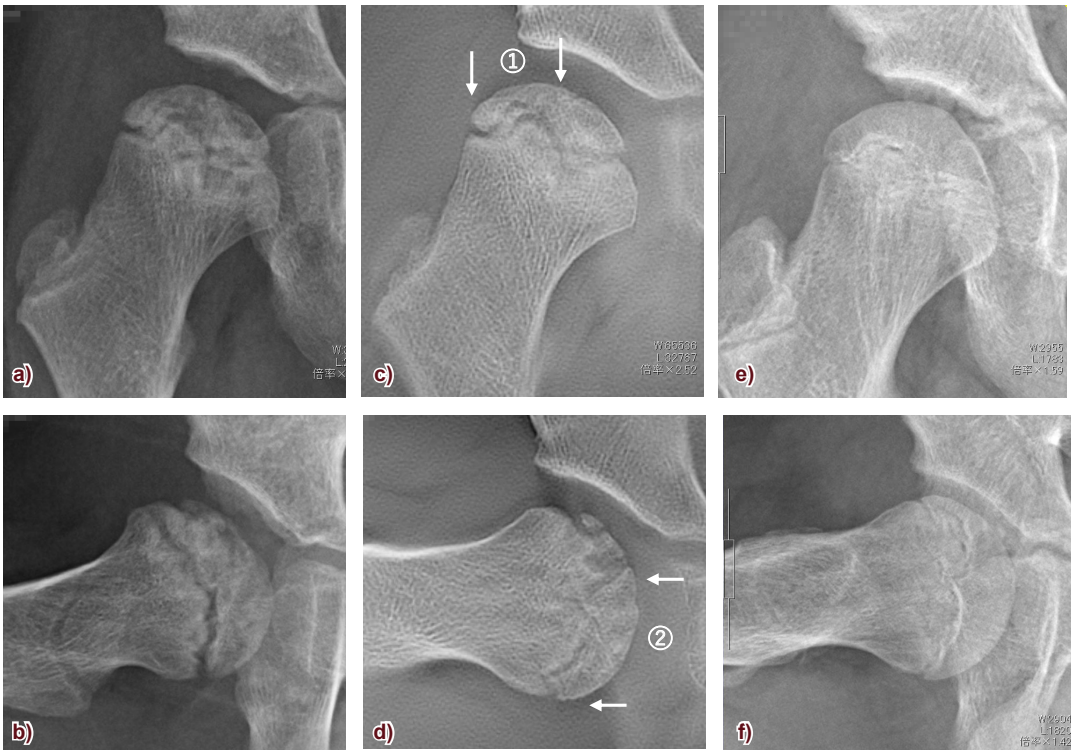

Fig. 7 Assessment of mild disease (Perthes disease of the right hip, aged 8 years)
Initial plain radiography: **a)** AP image **b)** Lateral image (Laurence view)
Initial Tomosynthesis: **c)** AP tomographic image **d)** Lateral image (Laurence view)
Plain radiography after 2 years (aged 10 years): **e)** AP image **f)** Lateral image (Laurence view)
① Intact lateral portion of the epiphysis ② Intact posterior portion of the epiphysis

As the age at onset increases, the phases of necrotic bone resorption and bone repair become less distinct and less sequential; instead, these phases tend to coexist, resulting in the fragmentation phase. Consequently, interpretation of the fragmented epiphysis becomes more difficult. If osteonecrosis involves less than 50% of the epiphysis, the disease is considered mild, corresponding to Catterall groups 1 and 2. Severity can also be assessed based on whether the lateral one-third of the epiphysis (lateral pillar) is preserved, corresponding to Herring groups A and B. In this case, the intact regions of the fragmented epiphysis were unclear on plain radiographs, however, Tomosynthesis clearly demonstrated preservation of the lateral one-third and posterior portion of the epiphysis, and the disease was classified as mild.

3.2 Osteochondral Lesions of the Talus (Figs. 8, 9)

Osteochondral lesions of the talus occur across all age groups, often related to sports injuries and other causes, and are most commonly located on the medial or lateral aspects. In contrast, central lesions are rare and are more frequently observed in children younger than 10 years. Conservative management is generally preferred. Although the clinical course is often prolonged, imaging plays an important role in assessing reparative progression. Tomosynthesis can be performed in flexible limb positions, and even in serial examinations, highly reproducible images can be obtained, allowing reliable longitudinal comparison of the lesion. The progressive decrease in the proportion of the lesion involving the weight-bearing surface of the talar trochlea, followed by eventual healing, can be clearly visualized. This also facilitates patient and family understanding and supports shared decision-making regarding treatment.

4. Summary

- In pediatric joint diseases, incomplete ossification of the epiphyses and the presence of physes pose challenges for imaging interpretation.
- For this reason, epiphyseal lesions are often difficult to clearly visualize on plain radiography, particularly in regions where multiple bones overlap, such as the hip joint and foot.
- Tomosynthesis enables acquisition of multiple consecutive tomographic images parallel to the detector plane from a single exposure and offers several advantages, including high-resolution images with reduced overlap, flexible patient positioning, and lower radiation dose compared with CT.
- In pediatric orthopedics, Tomosynthesis provides valuable diagnostic information in hip disorders such as Perthes disease and foot disorders such as osteochondral lesions of the talus, highlighting its clinical utility.

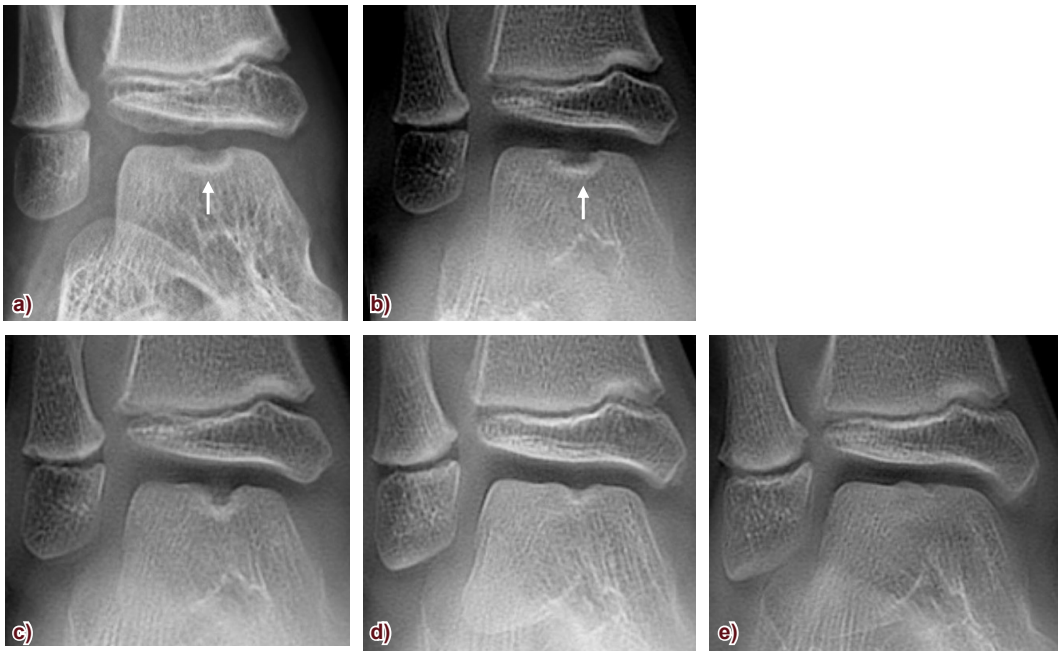

Fig. 8 Clinical course (Right osteochondral lesion of the talus, aged 6 years)
Initial plain radiography: **a)** AP image
Initial Tomosynthesis: **b)** AP tomographic image
Follow-up Tomosynthesis: **c)** After 5 months **d)** After 29 months **e)** After 41 months

At the initial visit, plain radiography showed a depressed lesion of the talar dome with indistinct margins. Tomosynthesis clearly demonstrated a depression extending from the subchondral region into the deeper portion.
After 5 months, the deeper portion had been repaired, and the lesion appeared as a simple depression. After 29 months, further repair was observed, and the lesion became smaller and more focal. After 41 months, the lesion had completely healed.

Fig. 9 Clinical course (Right osteochondral lesion of the talus, aged 8 years)
Tomosynthesis: **a)** AP tomographic image at the initial visit
b) After 4 months **c)** After 8 months **d)** After 14 months

At the initial visit, plain radiography showed a depressed lesion of the talar dome with indistinct margins. Tomosynthesis demonstrated a clear lesion extending into the deeper portion, involving slightly less than half of the subchondral region.
After 4 months, the lesion decreased in width, and repair of the deeper portion with irregular margins was observed. After 8 months, the lesion appeared as a shallow depression, and after 14 months, it had almost completely healed.

References

1) Catterall A: The natural history of Perthes' disease. J Bone Joint Surg 53B: 37–53, 1971.
2) Herring JA et al: Legg-Calve-Perthes disease. J Bone Joint Surg 86A: 2103–2120, 2004.

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