

# Emphasizing the Diagnostic Value of Digital Tomosynthesis in Detecting Hip Fractures

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**Abbreviations:** avascular necrosis (AVN), digital tomosynthesis (DTS), musculoskeletal (MSK), electronic medical record (EMR), computed tomography (CT), magnetic resonance imaging (MRI)

## ABSTRACT

Our institution recently implemented the use of digital tomosynthesis (DTS) to workup emergency room patients with suspected hip fractures after initial negative or indeterminate radiographs. Our purpose is to evaluate the diagnostic accuracy of DTS for hip fracture detection. We performed a retrospective review of all DTS studies over a 17-month period (July 2017 to November 2018). The results of the radiographs and DTS were recorded as either positive or negative for fracture based on the radiology report. Our reference standard for a fracture was either confirmation on subsequent CT or MRI from the same visit or documentation of clinical findings supportive of a fracture in the patient's electronic medical record. For patients with negative DTS who did not undergo subsequent cross-sectional imaging, a missed fracture was excluded if they did not return within 30 days with a confirmed fracture. Among 91 patients, there were 34 confirmed fractures—sites including, 7 femoral necks, 10 pubic rami, and 7 greater trochanters. DTS was positive for fracture in 29 patients; 28 of these fractures were true positives, 6 confirmed on cross-sectional imaging, and 22 confirmed clinically. One false positive was observed in a patient with no clinical evidence of a fracture. Six fractures were not detected by tomosynthesis but confirmed on CT/MRI. The sensitivity and specificity of DTS are 82% and 98%, respectively, compared to that of radiographs alone at 47% and 96%, respectively. DTS is a promising adjunct to radiographs for hip fracture detection in an emergency department.

## INTRODUCTION

More than 250 000 hip fractures occur in the United States annually, which carry an estimated mortality rate ranging from 14% to 36% (1). Worldwide, the rate of hip fractures varies as much as 10-fold between countries but is approximately >150/100 000 persons in North America and between 100 and 150/100 000 in most of Europe (2). Early diagnosis is important because an operative delay of >2 days doubles mortality (3). Missed nondisplaced fractures are at risk for avascular necrosis, or subsequent displacement, resulting in the need for more complicated operations, increased in-hospital time, and longer rehabilitation time (4, 5). Not surprisingly, missed orthopedic injuries are the leading cause of lawsuits against emergency room physicians (6). Detection of hip fractures is usually straightforward with standard orthogonal radiographs; however, occult hip fractures have an estimated incidence of 2%–10% (7, 8). This is particularly problematic in the elderly population in whom radiographic detection is hindered by osteoporosis, advanced arthritis, and suboptimal patient positioning. In these cases, alternative imaging modalities are used to exclude an occult fracture (9).

Magnetic resonance imaging (MRI) is considered the gold standard investigation (10–13) and has higher sensitivity and specificity than computed tomography (CT) (7, 14); however, MRI is more expensive, time-consuming, and not readily available, particularly after-hours. CT is more available and cost-effective, but it uses ionizing radiation, is not as sensitive as MRI, and can miss trabecular fractures and soft tissue injuries (9).

Digital tomosynthesis (DTS) uses a standard linear accelerator x-ray system that produces a series of low-dose images with a single sweep of the x-ray tube (15). A 10-second linear sweep produces ~60 low-dose exposures that are reconstructed in the plane of the detector at slice thicknesses of 1–10 mm (16). This technology has shown utility predominantly in breast (17) and thoracic imaging (18). Musculoskeletal applications have focused on imaging orthopedic hardware, in which metallic artifacts can limit CT and MRI assessment (19–21). The superior anatomical detail of DTS proves its capability to detect fractures not identified on plain radiographs (22). For wrist fractures, DTS has the advantage of improved sensitivity and specificity over radiographs (23). Although less sensitive than CT for wrist fractures,

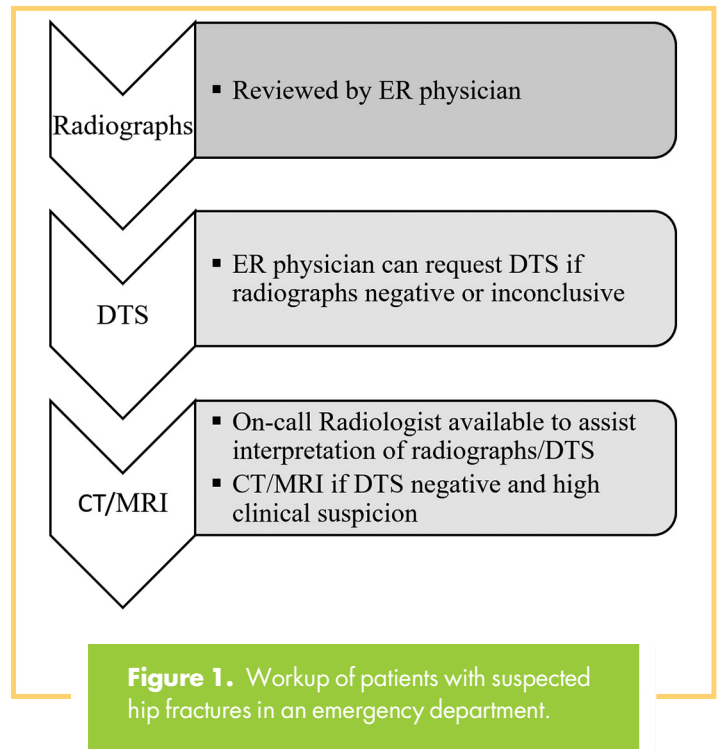
the major advantage of DTS over CT is its much lower radiation dose. In particular, for hip examinations using DTS, the effective dose is 0.82 mSv compared to 10.5 mSv for that using multidetector CT, approximately 13 times lower (24). There is limited research on the use of DTS in the detection of hip fractures; however, a recent Welsh study in 2015 of 41 patients concluded that tomosynthesis can be used for the assessment of suspected femoral neck fractures and further identification of patients requiring additional cross-sectional imaging (25).

We recently completed a pilot project in the Emergency Department at our tertiary care academic hospital, where patients undergoing radiography for a suspected hip fracture underwent DTS if no obvious fracture was seen by the medical radiation technologist performing the radiograph. The tomographic images were then reviewed and reported by a musculoskeletal (MSK) fellowship trained radiologist. This pilot study included 62 patients, 15 of whom had fractures. DTS identified 7 fractures not seen on radiography by the reporting radiologist. This showed promising results regarding the application of tomosynthesis for the detection of occult fractures, but limitations included a small sample size and reliance on the technologist to determine if DTS was needed. The images were also reviewed by only one MSK fellowship trained radiologist. However, based on the results of this pilot project, and following departmental training of staff radiologists, emergency physicians, residents, and fellows with seminars and a case file, we implemented the routine use of DTS into clinical practice for the diagnosis of occult hip fractures. This was done in partnership with the Emergency Department and the Orthopedic Surgery Department at our hospital.

A schematic regarding the workflow for assessing patients with possible hip fractures at our hospital is shown in Figure 1. First, the patient is assessed by the emergency physician and imaged with standard orthogonal radiographs. If there is no definite fracture seen, the emergency physician can request DTS of the hip as the next step. Initial interpretation is provided by the ordering physician or the radiologist on-call by request. A formal radiologist report is issued subsequently within 24 hours. If DTS is negative or inconclusive and there is high clinical suspicion for a fracture, CT or MRI can be requested with radiology approval. Although this workflow was put forth as the departmental recommendation, we realized not all emergency physicians will follow this algorithm. The purpose of our current investigation is to assess the diagnostic value of DTS in routine practice for the workup of suspected hip fractures in an emergency department.

**METHODOLOGY**

Following research ethics board approval, we conducted a retrospective review of all DTS examinations of the hips performed between July 2017 and November 2018 at our tertiary care academic hospital. This study period captures the newly implemented standard practice guideline regarding workup of hip fractures presented in Figure 1. We identified our patients by searching PACS (picture archiving and communication system) in the specified time period with the keyword “tomograms.” This is the title given to all DTS examinations at our hospital. We included all patients who underwent hip or pelvis DTS



**Figure 1.** Workup of patients with suspected hip fractures in an emergency department.

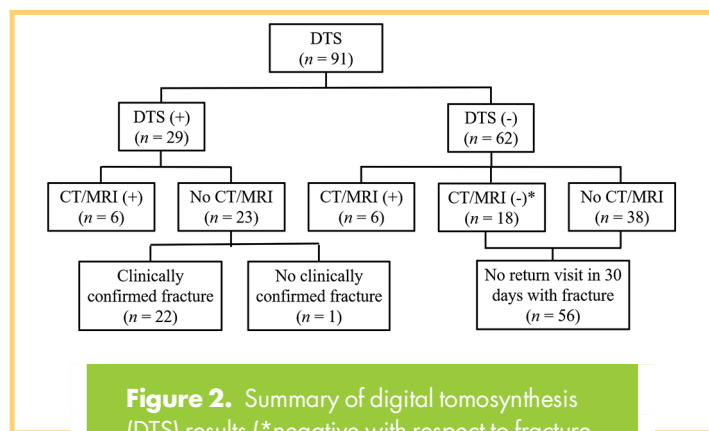
examinations to assess for hip fracture and excluded other examination types.

All examinations were acquired in the coronal plane using a Discovery XR650 system with VolumeRAD Digital Tomosynthesis (GE Healthcare, Chicago, IL). The majority of cases were reported by MSK fellowship trained radiologists. Cases assessed on weekends or holidays were reported by non-MSK fellowship trained radiologists. Final reports were issued within 24 hours of image acquisition.

We reviewed the reports of all radiographs and DTS examinations and tabulated the results. We also documented results for patients who underwent subsequent CT or MRI to use as a reference standard. For our statistical analysis, we considered a study

**Table 1.** Population Characteristics

Variable	Value (%)
Patient demographics (n = 91)	
Male	32 (35%)
Female	59 (65%)
Age (years ± 1 SD)	80 ± 13
Fractures (n = 34)	
Femoral neck	7 (21%)
Intertrochanteric	1 (3%)
Subtrochanteric	1 (3%)
Pubic Ramus	10 (30%)
Acetabular	5 (15%)
Base of greater trochanter	7 (21%)
Other	3 (9%)



**Figure 2.** Summary of digital tomosynthesis (DTS) results (\*negative with respect to fracture only).

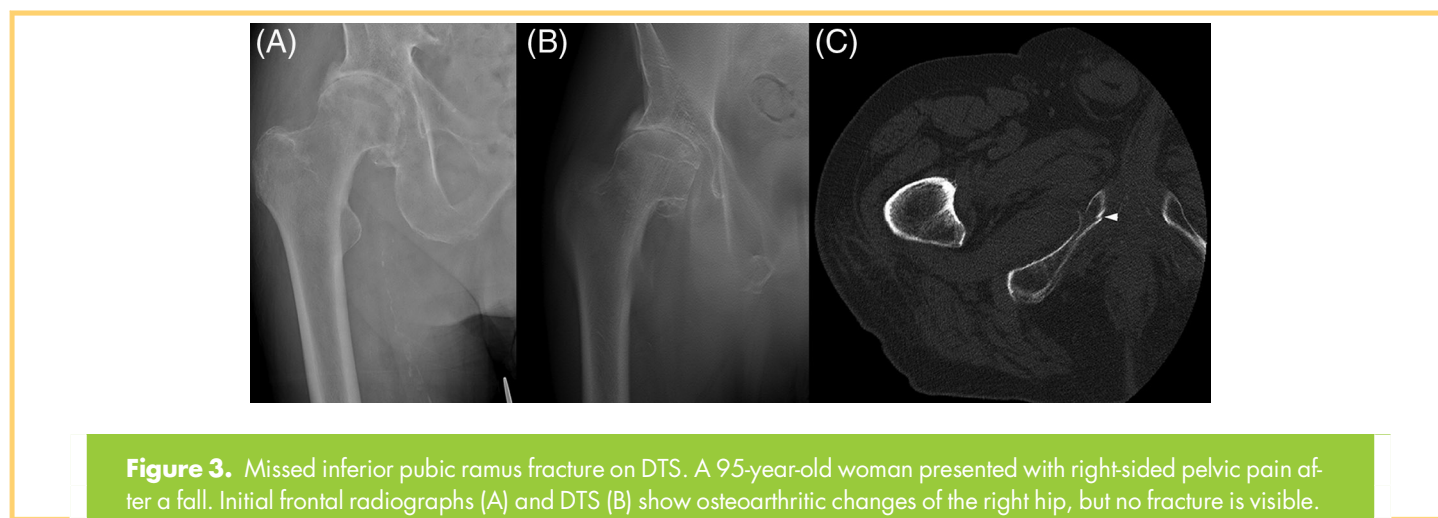
positive if the radiologist clearly stated in their report that a fracture was present. The fractures were categorized based on the pattern (ie, femoral neck, intertrochanteric, subtrochanteric, pubic ramus, acetabular, base of greater trochanter, and other). A study was considered negative if the radiologist clearly stated, “no fracture.” If the radiologist reported a “possible” or “suspected” fracture, it was still treated as a negative result for the purposes of statistical analysis, as a firm diagnosis could not be made. These patients were usually further assessed with cross-sectional imaging. Our reference standard for a fracture was confirmation on subsequent CT or MRI examination, if available. For patients with positive DTS who did not undergo further cross-sectional imaging, we reviewed the electronic medical records to confirm concordant clinical evidence of fracture from the consultation transcriptions (ie, documented history of trauma, difficulty ambulating, hip pain, and tenderness on examination). For patients with negative DTS who did not have subsequent cross-sectional imaging, we reviewed the electronic medical record to determine if they returned within 30 days of the initial visit with a confirmed fracture.

From these data, we were able to determine the sensitivity and specificity for detecting hip fractures using DTS compared with using radiographs alone.

**RESULTS**

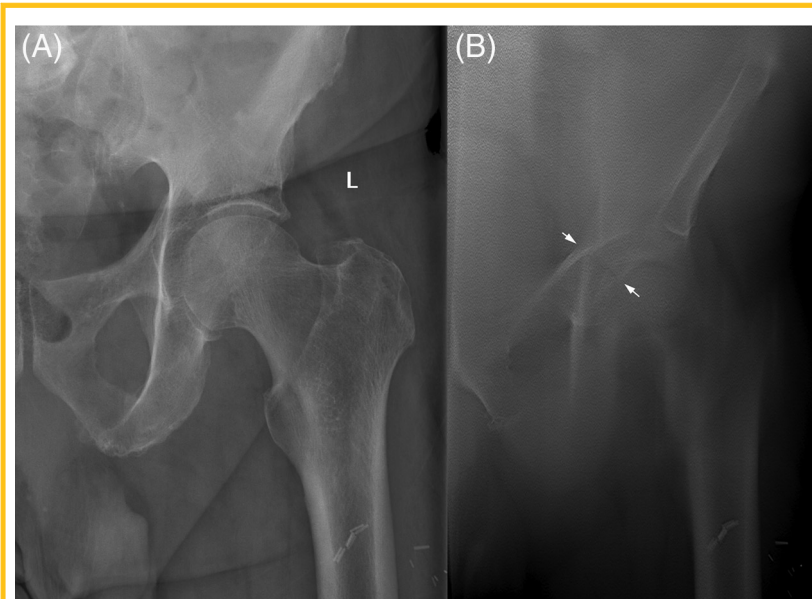
We identified 91 patients who underwent DTS of the hip during our study period (Table 1). All requests were made by either emergency physicians or orthopedic surgeons for patients presenting to the Emergency Department to assess for fracture. In total, 65% of patients were female, and the average age of our population was 80 years old. All patients underwent radiographs prior to DTS. In total, 26 patients underwent subsequent CT and 5 underwent subsequent MRI. One patient had both CT and MRI to characterize an ischial tuberosity avulsion and high-grade hamstrings tendon tear. There were 34 confirmed fractures in our study population, including 7 fractures of the femoral neck, 7 of the greater trochanter, and 10 pubic rami fractures. A complete breakdown of fracture types is provided in Table 1.

DTS was reported positive in 29 patients (Figure 2). Fractures were confirmed in 6 of these patients with cross-sectional imaging and clinically in 22 patients upon review of the medical record. In 1 patient, clinical evidence of a fracture was not documented in the chart and thus considered false positive. This patient was admitted to the Internal Medicine unit for treatment of delirium induced by a urinary tract infection. DTS was negative in 62 patients, among whom 6 missed fractures diagnosed on subsequent cross-sectional imaging. The locations of the missed fractures were at the pubic rami (3), anterior acetabular column (1), lesser trochanter (1), and iliac wing (1). These were all managed conservatively. An example of a missed pubic ramus fracture is presented in Figure 3. The remaining 18 CT/MRI examinations were negative for fracture, but 7 of these showed alternative diagnoses that could explain hip pain, including avascular necrosis of the femoral head, intramuscular hematoma, iliopsoas tendon injury, gluteus maximums calcific tendonitis, and splenic infarcts. None of the patients with negative DTS returned within 30 days with a confirmed fracture.



**Figure 3.** Missed inferior pubic ramus fracture on DTS. A 95-year-old woman presented with right-sided pelvic pain after a fall. Initial frontal radiographs (A) and DTS (B) show osteoarthritic changes of the right hip, but no fracture is visible. Subsequent axial computed tomography (CT) (C) identified a nondisplaced fracture of the inferior pubic ramus. Note the fracture line is oriented in the coronal plane, which may account for its occult appearance on DTS.





**Figure 4.** Nondisplaced anterior acetabular fracture. A 75-year-old man with posttraumatic left hip pain had no fracture identified by the reporting radiologist on initial radiographic assessment (A). The iliopectineal and ilioischial lines are intact. DTS performed subsequently (B) revealed a subtle nondisplaced fracture of the anterior acetabulum (arrows). The patient was assessed by an orthopedic surgeon who confirmed clinical findings consistent with the fracture, and the patient was managed conservatively.

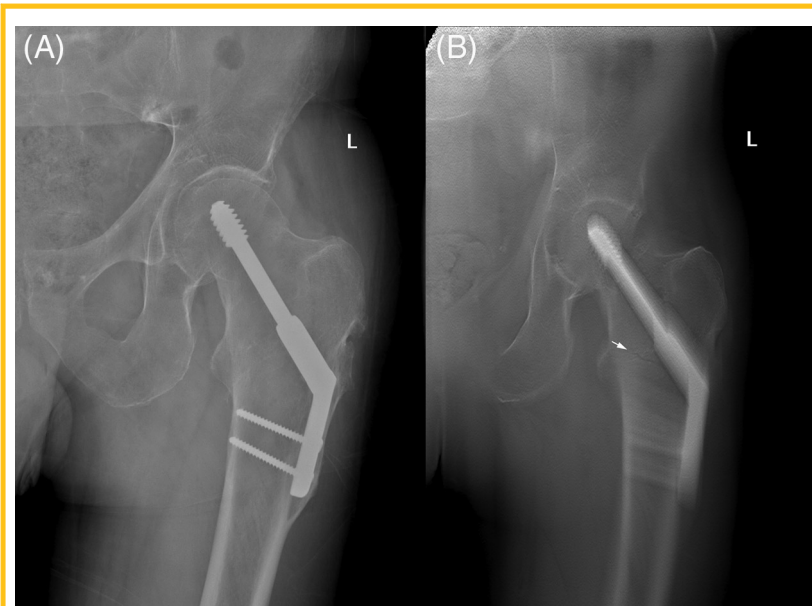
Radiographs were reported positive in 18 cases, 16 of which were confirmed and 2 were found to be false positives. Of the 73 patients with negative radiographs, 18 were determined to be false negatives. Examples of fractures missed on radiographs include an anterior acetabulum fracture (Figure 4) and periprosthetic intertrochanteric fracture (Figure 5). Other fractures subtle on initial radiographs were better depicted on DTS, including a greater trochanter fracture (Figure 6) and a femoral neck fracture (Figure 7).

In summary, there were 34 patients with confirmed fractures. DTS yielded 6 false negatives and 1 false positive, and so for fracture detection, the DTS's overall sensitivity is 82% and specificity 98%. In comparison, radiographs alone were 47% sensitive and 96% specific.

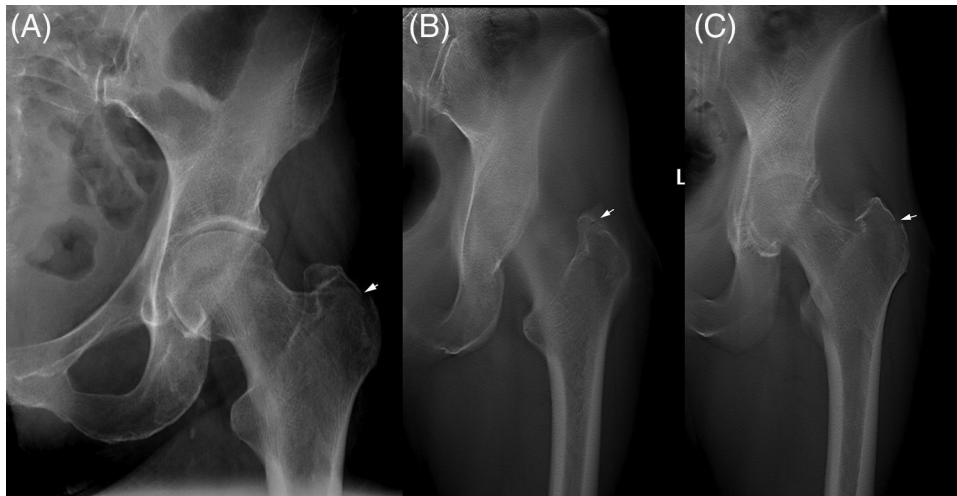
## DISCUSSION

DTS offers improved sensitivity for the detection of hip and pelvic fractures in patients presenting to the Emergency Department with hip pain compared with radiography alone. Some possible reasons for the improved detection include superior anatomical detail and minimization of summation artifact of overlapping shadows. For example, in Figure 8, the radiograph of a patient is heavily attenuated by overlapping soft tissues and the bones are demineralized, which obscures the superior pubic ramus fracture. DTS can also provide clarification of overlapping shadows that could potentially mimic a fracture, as shown in Figure 9.

A previous study by Al-Mokhtar *et al.* reported a sensitivity of 67% for femoral neck fractures only, and other fractures, such



**Figure 5.** Periprosthetic intertrochanteric fracture occult on radiograph. A 71-year-old man with previous dynamic hip screw fixation presented with left hip pain after a fall. The initial radiograph (A) showed stable positioning and alignment of the hardware with no acute fracture. On DTS performed subsequently (B), a nondisplaced intertrochanteric fracture was identified (arrow). An orthopedic surgery referral was initiated, and the patient was managed conservatively.



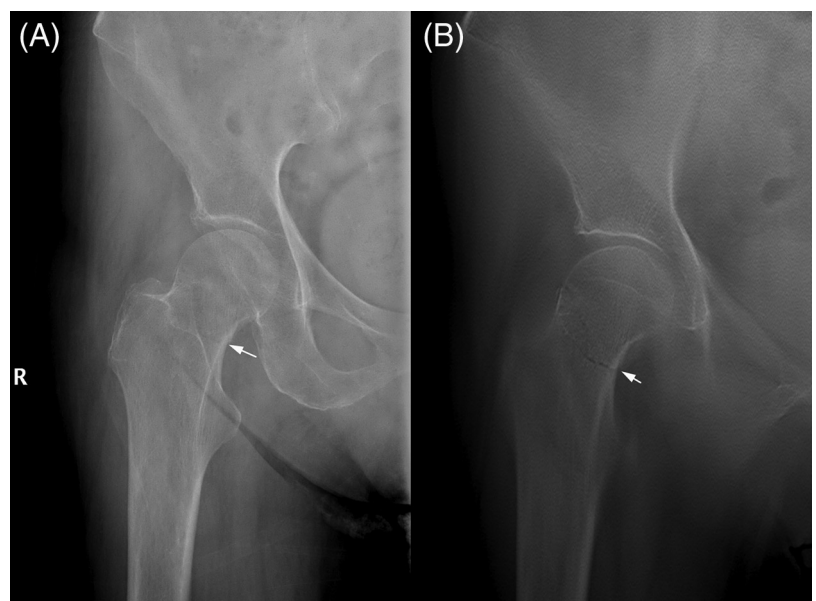
**Figure 6.** Base of greater trochanter fracture confirmed on DTS. A 66-year-old woman with posttraumatic left hip pain had an initial radiograph (A) showing a nondisplaced fracture of the greater trochanter (arrow). DTS performed subsequently (B, C) confirms the finding and better delineates the orientation of the fracture line, excluding intertrochanteric extension.

as pubic rami fractures, were not included in their reported sensitivity (25). Our reported sensitivity of 82% is an overall sensitivity for detection of any hip or pelvis fracture, which may, in part, explain the difference. Further studies will be required to determine if there are specific differences in the detection rate for different fracture types using DTS.

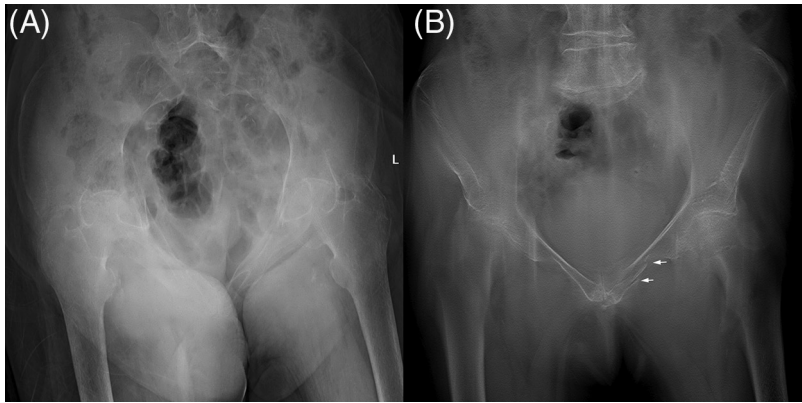
The first limitation of our study design is assuming all emergency physicians in our hospital follow the proposed algorithm presented in Figure 1 for working up patients with suspected hip fractures. There are likely patients who went directly to CT after

negative radiographs. As we are interested in the diagnostic utility of DTS, these patients would be excluded anyway, but this introduces a potential bias in how our patients were selected. However, we have overall received positive feedback from our emergency physician colleagues who have indicated that their confidence with using DTS when uncertain about radiographic findings has improved with experience.

Our study is a retrospective review of a clinical practice. Although we are reporting the sensitivity and specificity of DTS for hip fractures, it is important to address several limitations.



**Figure 7.** Femoral neck fracture confirmed on DTS. An 82-year-old woman with posttraumatic right hip pain and inability to weight bear underwent radiography (A) which showed a nondisplaced femoral neck fracture (arrow). The hip joint space is preserved. DTS performed subsequently (B) clearly shows the fracture line and medial cortical disruption (arrow). The patient was managed with cannulated screw fixation.



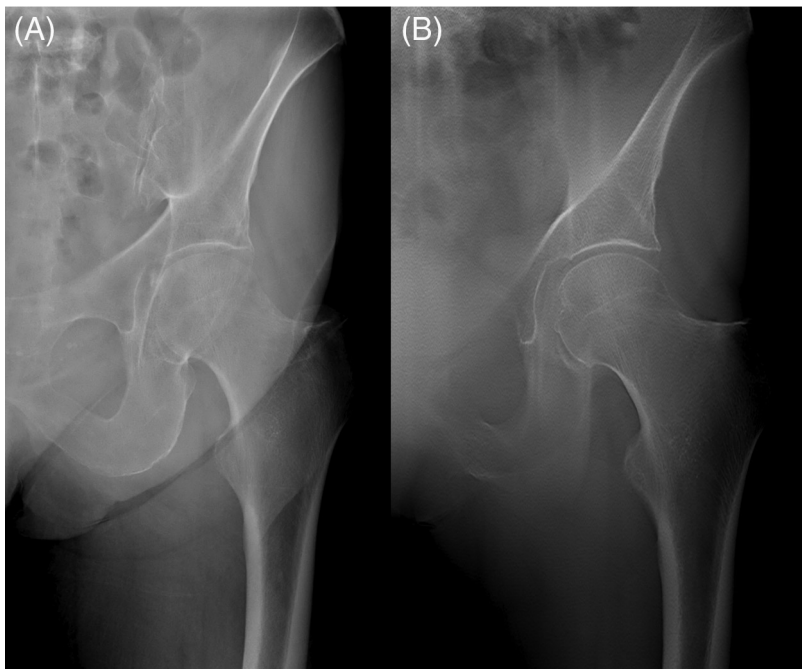
**Figure 8.** Reduction of summation artifact from overlapping shadows. In this 99-year-old woman, assessment of pelvic radiographs (A) is significantly limited because of artifacts from overlying soft tissues, bony demineralization, and advanced osteoarthritic changes. DTS (B) of the whole pelvis minimizes these artifacts and allows for detection of multiple left-sided superior pubic ramus fractures (arrows).

First, it would be more accurate to use the same reference standard for all patients (ie, MRI). Because of limitations in resources, this was not a realistic option. Our negative reference standard of a no return visit in 30 days assumes that the patient would return to our hospital or a nearby hospital that is part of the same PACS and electronic medical record network. It is possible that some of these patients traveled to another city on a subsequent day with a confirmed fracture that would not be captured by our methods.

The low sensitivity of radiographs is not surprising, as our study is biased toward identifying patients with occult fractures. However, 18 patients with positive radiographs still underwent DTS. A probable reason for this is related to the workflow of assessing these patients. In a busy emergency department, the final radiology report is often not available until after an emergency physician has ordered subsequent imaging. The clinician either did not see the fracture or was not certain in the diagnosis

based on radiograph only. DTS provides additional information in an efficient and cost-effective manner that can increase the confidence of the reader. In these cases, the radiologist may report the radiograph as positive with the benefit of also reviewing the DTS. It is less likely that the result of a DTS report would be biased by subsequent CT or MRI, as these investigations need approval by the on-call radiologist who would review the imaging already performed at the time of the request. Patients who underwent subsequent CT after a positive DTS did so for further fracture characterization and preoperative planning at the request of orthopedic surgery (ie, complex acetabular fractures).

It is important to acknowledge that DTS is not as sensitive as CT or MRI, and we are not advocating that it should replace further investigation in cases of high clinical suspicion. Rather, DTS may have a role in reducing the need for higher-level cross-sectional imaging by better showing fractures not seen on the



**Figure 9.** Reduction of summation artifact from overlapping shadows. An 82-year-old woman underwent radiography (A) of the left hip that show no fracture; however, there are overlapping skin folds potentially mimicking a fracture. DTS (B) eliminates these skin folds and provides superior anatomical detail of the osseous structures. No fracture was identified, and the patient was discharged, with no return visit documented.



radiograph. A negative DTS in a patient with the inability to weight bear or other highly suspicious clinical findings should not preclude additional evaluation. Fractures missed with DTS include those that are oriented in the coronal plane, which are difficult to detect without an orthogonal plane (Figure 3), or purely trabecular fractures. However, we emphasize that using DTS after radiography did not miss any surgical fractures in our population. Soft tissue injuries or other hip pathologies such as avascular necrosis are difficult to diagnose with DTS. This limitation is exemplified in our 7 patients with alternative diagnoses that could account for hip pain including tendon pathologies

only appreciated on MRI. The decision to pursue further imaging when soft tissue injuries are suspected should be guided by the clinical presentation and physical examination.

Digital tomosynthesis is a promising adjunct to radiography with improved detection of hip and pelvic fractures. Its use in the workup of patients with suspected fractures presenting to an emergency department may decrease the need for CT and MRI. However, it is important to recognize that DTS remains less sensitive than CT, and MRI is the gold standard investigation. In cases where there is high clinical suspicion, a negative DTS should not preclude further imaging evaluation.

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Conflict of Interest: None reported.

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