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Tomosynthesis of the thoracic spine – added value in diagnosing vertebral fractures in the elderly

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Abstract

Background: Thoracic spine radiography becomes more difficult with age. Tomosynthesis is a low-dose tomographic extension of radiography which may facilitate thoracic spine evaluation. This study assessed the added value of tomosynthesis in imaging of the thoracic spine in the elderly.
Methods: Four observers compared the image quality of 50 consecutive thoracic spine radiography and tomosynthesis data sets from 48 patients (median age; 67 years, range 55-92 years) on a number of image quality criteria. Observer variation was determined by free-marginal multirater kappa. The conversion factor and effective dose were determined from the dose-area-product values.
Results: For all observers significantly more vertebrae were seen with tomosynthesis than with radiography (mean 12.4/9.3, $P<0.001$) as well as significantly more fractures (mean 0.9/0.7, $P=0.017$). The image quality score for tomosynthesis was significantly higher than for radiography, for all evaluated structures. Tomosynthesis took longer to evaluate than radiography. Despite this, all observers scored a clear preference for tomosynthesis. Observer agreement was substantial (mean $\kappa=0.73$, range 0.51-0.94). The calibration or conversion factor was 0.11 mSv/Gycm^2 for the combined examination. The resulting effective dose was 0.87 mSv.
Conclusion: Tomosynthesis can increase the detection rate of thoracic vertebral fractures in the elderly, at low added radiation dose.

Key points

- Tomosynthesis helps evaluate the thoracic spine in the elderly.
- Observer agreement for thoracic spine tomosynthesis was substantial (mean κ=0.73).
- Significantly more vertebrae and significantly more fractures were seen with tomosynthesis.
- Tomosynthesis took longer to evaluate than radiography.
- There was a clear preference among all observers for tomosynthesis over radiography.

Keywords

Thoracic vertebrae; Radiography; Tomography, X-Ray; Image quality; Fracture;

Introduction

Radiography of the thoracic spine in the elderly often becomes more difficult with advancing age as a result of a combination of progression of osteoporosis and increased density of pulmonary structures. This makes it difficult to evaluate the thoracic spine for osteoporotic compression fractures [1] as well as for destructions and other lesions, which may require the use of other imaging modalities. Thoracic spine tomography [2, 3] was frequently used before the advent of computed tomography (CT). Autotomography of the thoracic spine was also frequently used earlier, where the patient was allowed to slowly move the arms or slowly breathe during long exposures [4], which is harder to perform well today, with modern generators and detectors performing at short exposure times. Instead, CT [5] or magnetic resonance imaging (MRI) [6] may be used. The drawbacks are, however, the need to transfer the patient from the radiography room to the CT or MRI suite, or to reschedule the patient, leading to increased length of stay in the radiography department for the patient, and increased waiting time for a comprehensive diagnosis. Other drawbacks are increased radiation dose with CT, and contraindications to MRI (e.g. some metallic implants and pacemakers), and the relative contraindication of claustrophobia. In addition, examination with CT or MRI is costly compared with radiography supplemented by tomosynthesis, where the current price at the authors' institution for radiography of the thoracic spine is EUR 63, radiography including tomosynthesis EUR 127, CT EUR 176, and MRI EUR 264.

Tomosynthesis is a low-dose tomographic addition to conventional radiography which has been available since about 2008, where information from a large number of low-dose exposures from a moving X-ray tube towards a stationary detector are used to reconstruct an arbitrary number of tomographic sections [7]. The technique has previously been evaluated in mainly chest radiography [8–10] and mammography [11], but has also been applied in abdominal imaging [12] and in musculoskeletal radiography. In a pilot study on scaphoid fracture detection at the two-weeks' follow-up of suspect occult fracture [13], radiography detected one scaphoid waist fracture not detected at radiography at the time of the trauma, while tomosynthesis detected this fracture and two additional fractures, not seen with radiography. In another study on 100 patients with wrist trauma [14], sensitivity of radiography for any fracture was 61-80 %, sensitivity of tomosynthesis 77-87 %, and of CT 86-95 %. It has also been used for evaluation of fracture healing [15], with similar results. In peripheral arthritis imaging, it has been shown to be better than radiography but not as good as CT [16] but almost as good as MRI in detecting erosions [17]. Digital linear tomosynthesis in musculoskeletal applications should not be seen as a tool to replace CT, but as an improvement on radiography to provide better imaging at low cost and low added dose.

Tomosynthesis is performed with motorized conventional radiography equipment only using additional software, without the need for new equipment or extra space. The added dose is limited [8, 18]. It thus has the potential to add to the diagnostic information from thoracic spine radiography at comparatively limited added radiation dose and cost.

The purpose of the current study was to evaluate the added value from tomosynthesis in imaging of the thoracic spine in the elderly.

Materials and methods

Patients

This prospective study was approved by the local ethics committee at Lund University (450/2008). Fifty-four examinations on 52 patients who accepted to participate were consecutively included after informed consent. Inclusion criteria were age above 50 years, ability to understand written and oral instructions, and referral for radiography of the thoracic spine. Four examinations were excluded: three for technical reasons where the study had been centered on the lower half of the thoracic spine and the proximal half had not been included, and in one recorded patient the tomosynthesis examination had not been performed. Fifty paired examinations with radiography and tomosynthesis of the thoracic spine were thus available for analysis.

In 48 patients, median age was 67 years (range 55-92). Median age for 13 men was 67 years (range 59-83), for 35 women 68 years (range 55-92). The most common indication for examination was thoracic spinal pain (n=26), followed by myeloma (n=13). Seven other indications were each indicated for 1-3 examinations.

Radiography and tomosynthesis

Radiography and tomosynthesis of the thoracic spine were performed on a commercially available radiography system (Definium 8000 with VolumeRAD option; GE Healthcare, Chalfont St. Giles, UK). The radiography examination consisted of 1) an anterior-posterior (AP) exposure at 75 kVp and 0.1 mm Cu as added filtration followed by 2) a lateral exposure at 80 kVp which is also used by the system as a scout for 3) the tomosynthesis sweep. The lateral tomosynthesis scan was performed using the VolumeRad software. The tomosynthesis system and its principles have been described in detail previously [7, 8, 18, 19]. Briefly, 60 low-dose exposures by the moving X-ray tube from tube angles -15 degrees to +15 degrees on a stationary detector are used to reconstruct about 60 tomographic sections of arbitrary thickness. The sections have a sharp focus plane and with increasing distance structures outside the focus plane become increasingly blurred.

Image analysis

All available lateral thoracic spine images and the lateral tomosynthesis scan were assessed by four observers in random order at different sessions. The randomization was different for each observer. For each patient, the radiographs were scored first, followed by the scoring of the tomosynthesis scan.

First, the number of clearly visualized contiguous vertebrae seen on radiography was recorded, as well as the number of clearly diagnosed vertebral fractures, followed by the same assessment on tomosynthesis. Fractured vertebrae were defined as having less anterior height compared with neighboring vertebrae, having a loss of vertical continuity, and as having end-plate deformities or cortical buckling. In addition, the semiquantitative grading appearances suggested by Genant et al. were taken into account [20]. All images and tomosynthesis scans were then compared in a visual grading analysis according to a modification of the European guidelines for multislice computed tomography (MSCT) quality criteria for lumbar spine CT 2004 [21], where the tomosynthesis scan was compared to the lateral thoracic spine radiograph(s), which served as reference, in three regions of the thoracic spine – the upper thoracic spine in the region of T3, the middle thoracic spine in the region of T7, and the lower thoracic spine in the region of T11. The regions were chosen to provide areas with different types of anatomic noise – the shoulders at the level of T3, pulmonary structures at the level of T3, and abdominal structures at the level of T11.

The following anatomic structures were judged on image quality: sharp reproduction of the upper and lower end-plate surfaces, sharp reproduction of the pedicles and intervertebral foramina, sharp reproduction of the spinous process, and sharp reproduction of trabecular and cortical bone. Each structure was scored from zero to four: 0 (the tomosynthesis scan was much worse than the reference), 1 (worse than reference), 2 (equal to reference), 3 (better than reference) and 4 (the tomosynthesis scan was much better than the reference).

Lastly, a general comparison between radiography and tomosynthesis was performed, scoring three statements from 0 to 4: how the experience of the image quality of tomosynthesis was compared to the reference (using the scoring levels above), if the observer experienced that the time needed to evaluate the tomosynthesis scan was longer than for radiography, and whether the observer would rather use tomosynthesis than radiography for evaluation of the thoracic spine (where the question included image quality, diagnostic confidence, and time used for evaluation). The scoring levels for the last two questions were: 0 (confident that the criterion is not fulfilled), 1 (somewhat confident that the criterion is not fulfilled), 2 (indecisive whether the criterion is fulfilled or not), 3 (somewhat confident that the criterion is fulfilled), and 4 (confident that the criterion is fulfilled).

Estimation of effective dose

The dose-area product (DAP) from the radiography system was retrieved from the Digital Imaging and Communications in Medicine (DICOM) data in the Picture Archiving and Communication System (PACS) for each of the two projections. In order to calculate the effective dose, E, a conversion factor E_{DAP}, was derived using the PCXMC version 2.0 [22] software package.

$$E = E_{DAP} * DAP \ \ [mSv]$$

Monte Carlo simulations were performed for an adult phantom, 170 cm high with a weight of 70 kg, using 10^7 photons. Organ doses are calculated based on the energy deposited in the simulation which includes organs specified according to ICRP 103 [23].

The derived tomosynthesis data set is however stored in the PACS without any reference to the original DAP values of the 60 exposures. Båth et al [24] have recently suggested a method to derive the effective dose from the exposure values of the scout image together with the DAP value and recently also verified it for thoracic spine tomosynthesis [25]. The total effective dose from all three data sets is then used to calculate E_{DAP}.

Statistics

Comparison between groups regarding number of visualized vertebrae and number of fractures were evaluated with a paired *t*-test. The data from the image quality scoring were highly skewed towards 3 and 4, i.e. better than reference. Data were therefore dichotomized into scores 0-1-2 (tomosynthesis worse than or equal to radiography) and 3-4 (tomosynthesis better than radiography). Statistical significance of the results was tested with one-sided binomial test of proportions. A *P*-value < 0.5 indicated statistical significance. The R statistical package version 3.1.1 (R Project for Statistical Computing, http://www.r-project.org/) and SPSS version 21 were used for statistical calculations. Observer agreement was assessed by Randolph's free-marginal multirater kappa [26] and percent agreement. Kappa (κ) values may be translated as 0 representing less than chance agreement, 0.01–0.20 slight agreement, 0.21–0.40 fair agreement, 0.41–0.60 moderate agreement, 0.61–0.80 substantial agreement, and 0.80–0.99 almost perfect agreement [27].

Results

The mean number of lateral radiographs was 1.4. All patients had one tomosynthesis scan, which was reconstructed into mean 52.7 sections with section thickness 2 mm (one study had been performed at 1 mm thickness). Of these, mean 23.1 of sections covered the thoracic spine, using a mean of 43.4 mm total width of the sections.

Number of vertebrae and vertebral fractures

For all observers, a mean of 9.3 vertebrae were visualized with radiography, and 12.4 with tomosynthesis, $p<0.001$. Slightly fewer fractures were seen with radiography, a mean of 0.7, than with tomosynthesis, 0.9, $p=0.017$. A longer contiguous span of the thoracic spine could thus be seen with tomosynthesis, and more fractures could be diagnosed (Figs. 1, 2).

Image quality

For all four observers, significantly more scores 3 and 4 (i.e., the tomosynthesis scan was better or much better than reference) than scores 0, 1 and 2 (i.e. the tomosynthesis scan was worse than or equal to radiography) were given for all evaluated structures ($p<0.001$) (Table 1).

For general image quality assessment, all given scores were above equal (3; n=59, 4; n=141) with a significant preference for the tomosynthesis scan ($p<0.001$).

Perceived time for evaluation

For all four observers, significantly more scores 3 (n=74) and 4 (n=115) than scores 0 (n=0), 1 (n=0) and 2 (n=11) were given for perceived time for evaluating the modalities ($p<0.001$), indicating that the tomosynthesis scan took longer to evaluate.

Preference of imaging modality

Despite the longer time used for evaluation of tomosynthesis, there was a very clear preference for tomosynthesis over radiography. For all four observers, significantly more scores 3 (n=21) and 4 (n=178) than scores 0 (n=0), 1 (n=0) and 2 (n=1) were given ($p<0.001$).

Observer variation

Using dichotomized data (score 0-2 vs. score 3-4) the mean free-marginal multirater kappa for all image quality assessments was 0.73 (Table 1), indicating substantial agreement, with percent agreement of 0.86. Observer agreement was better for the criteria visualization of the spinous process (κ=0.82, near-perfect agreement) and visually sharp reproduction of the cortex and trabecular bone (κ=0.85, near-perfect agreement) than for the criteria visually sharp reproduction of the end-plate structures (κ=0.58, moderate agreement) and reproduction of the pedicles and the intervertebral foramina (κ=0.67, substantial agreement).

Radiation dose

Out of the 50 examinations available, it turned out that during the first five consecutive examinations the dosimetry system, hence not affecting image quality, was poorly calibrated and these values have thus been excluded from the calculations, leaving 45 examinations suitable for dose calculations. The mean effective dose for the three projections were found to be 0.10 mSv (AP), 0,11 mSv (tomosynthesis scout) and finally 0.66 mSv for the lateral tomosynthesis sweep. These examinations were performed with the patients supine and resulted in a conversion factor of 0.11 mSv/$Gycm^2$ for the full examination consisting of a frontal, a lateral scout projection and the lateral tomosynthesis sweep.

Discussion

The current study has shown the improved detection of vertebral fractures with tomosynthesis of the thoracic spine in the elderly, where all four observers had significantly more scores indicating a preference for tomosynthesis than for radiography (199/1;$p<0.001$). The mean difference in image quality score was highly significant in favor of tomosynthesis. The results are thus similar to another visual grading analysis of anatomic structures using thoracic spine tomosynthesis [28]. Tomosynthesis also allowed for evaluation of significantly more vertebrae than the lateral projection of the thoracic spine, and also allowed for the detection of significantly more vertebral fractures.

In particular, tomosynthesis may have a value in diagnosing osteoporotic fractures of the thoracic spine, which often are under-recognized and under-reported [1]. The reason for under-recognizing fractures in the thoracic spine is often reduced image quality due to disturbing anatomic noise from the lung structures, which becomes more apparent with age concomitantly with a reduction of bone mineral density. Tomosynthesis can remove this anatomic noise (Fig. 1).

The resulting tomosynthesis images have a sharp focus plane and increasingly blurred surrounding structures with increased distance from the focus plane. The stated slice thickness is actually the slice increment.

The image appearance is thus different from both radiography and CT, and there is a learning curve when starting with tomosynthesis. In the current study tomosynthesis was performed in the lateral plane only, which limited the detection of fractures to those visible from lateral, i.e. vertebral compression fractures, whereas possible fractures visible in the AP projection such as lateral process fractures could not be detected. Another limitation is patients with scoliosis which is not uncommon among the elderly, where the visualization of the endplates would be more difficult. This, however, is even more a limitation with conventional radiography. The outer limits of the scoliosis can be included by adapting the slice increment to cover the entire scoliosis.

The increased radiation dose from tomosynthesis is moderate, within the same order of magnitude, compared with standard-dose CT. In the current study the total effective dose was 0.87 mSv for the entire study, including an AP radiograph, the lateral projection which also serves as the scout image for the tomosynthesis acquisition, and the tomosynthesis acquisition itself. The effective dose for thoracic spine radiography has been reported as average 1.0 mSv with a range from 0.6 to 1.4 mSv [29]. Reported figures for effective dose for CT from Sweden are 8.7 mSv for lumbar spine CT in 2006, and 6.6 mSv for chest CT [30]. Although no doses are given for thoracic spine CT, it is reasonable to suppose that the dose would be similar to chest CT. In a recent study by Svalkvist et al. [18] using the same examination technique as in the current study they reported a total dose of 0.59 mSv which is lower than in the current study. The patients examined in the current study were elderly patients and many presented with advanced kyphosis. The resulting effective dose did therefore increase slightly due to a larger volume that was exposed on the tomosynthesis scans (including the scout view) as can be seen in Fig. 1 and 2 and therefore a significantly larger spread in effective dose. The effective dose varied between 0.22 and 2.34 mSv, a ratio of 10.5 while Svalkvist et al. [18] showed a more homogeneous exposure pattern with a ratio of only 3.4.

In the current study image quality assessment was subjective, based on a modification of the European guidelines for multislice computed tomography (MSCT) quality criteria for lumbar spine CT 2004 [21]. The anatomic landmarks selected for image quality comparison (Table 1) are however somewhat coarse, and the number of visible vertebrae was added as a parameter to show the increased visibility of vertebrae in the shoulder region with tomosynthesis, and the number of detected vertebral fractures was added as a surrogate for detection of pathologic changes. In the current comparison there was no way to perform an objective image quality assessment which is possible when comparing different CT reconstruction algorithms or dose levels where signal-to-noise ratio or contrast-to-noise ratio may give an indication of image quality.

The number of observers is critical to an image quality comparison, in order to avoid personal bias and allow for differences of opinion. The exact number of observers is hard to determine, but in general more observers are better than fewer [31, 32].

The strengths of the current study are its prospective nature, the semiquantitative scoring, and the number of observers. Limitations are the lack of outcome reference and the lack of recording of pathology other than vertebral fractures. In this particular patient group, the prevalence of pathology other than vertebral fractures is low, and it would have been beneficial to have had a study population with a higher prevalence of pathologic findings to allow for systematic scoring of other pathology than vertebral fractures. The recording of the number of vertebrae and fractures on radiography and tomosynthesis was done in conjunction with each other which introduces recognition bias. However, as clinical experience from before study start indicated that the displayed length of the spine is always shorter with radiography than with tomosynthesis, the radiographs were evaluated first to ascertain that the same lengths of spine were evaluated on both modalities.

In conclusion, tomosynthesis is a good option to increase the performance of thoracic spine radiography in the elderly with anatomic structures shown in more detail, at low added radiation dose and low added cost. The current study has also shown the increased ability to detect pathologic changes with tomosynthesis.

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Figure legends

Fig. 1. A 92-year-old woman with severe osteoporosis and multiple osteoporotic compression fractures. A) One fracture was scored with radiography (arrow), B) three with tomosynthesis (arrows).

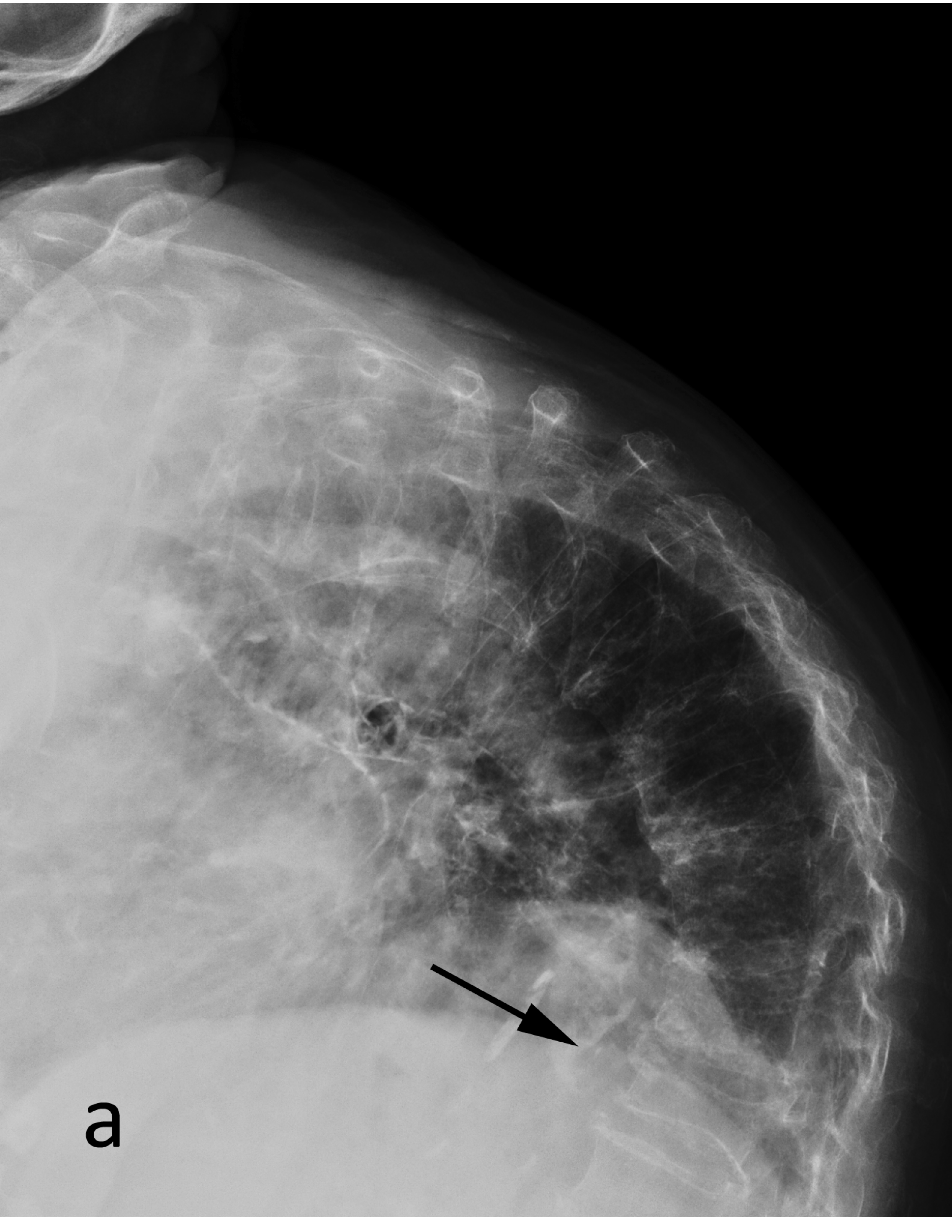
Fig. 2. An 83-year-old man with prostatatic cancer. No fractures were scored with either modality. Compared with A) radiography, B) more vertebrae were clearly seen with tomosynthesis, and the metastases were also more clearly seen.

Tables

Table 1. Frequency table over the image quality scores for all given scores by four observers (n=200).

Scoring level	Upper cervical spine				Middle cervical spine				Lower cervical spine			
	End-plates	Pedicles, foramina	Spinous process	Cortex, trabecular bone	End-plates	Pedicles, foramina	Spinous process	Cortex, trabecular bone	End-plates	Pedicles, foramina	Spinous process	Cortex, trabecular bone
0										1	1	
1			1	1			1					
2	37	29	7	6	44	21	9	16	23	15	15	3

3	97	103	42	123	97	101	47	118	84	93	83	128
4	66	68	150	70	59	78	143	66	93	91	101	69
Kappa	0.51	0.59	0.85	0.89	0.52	0.66	0.85	0.73	0.70	0.75	0.75	0.94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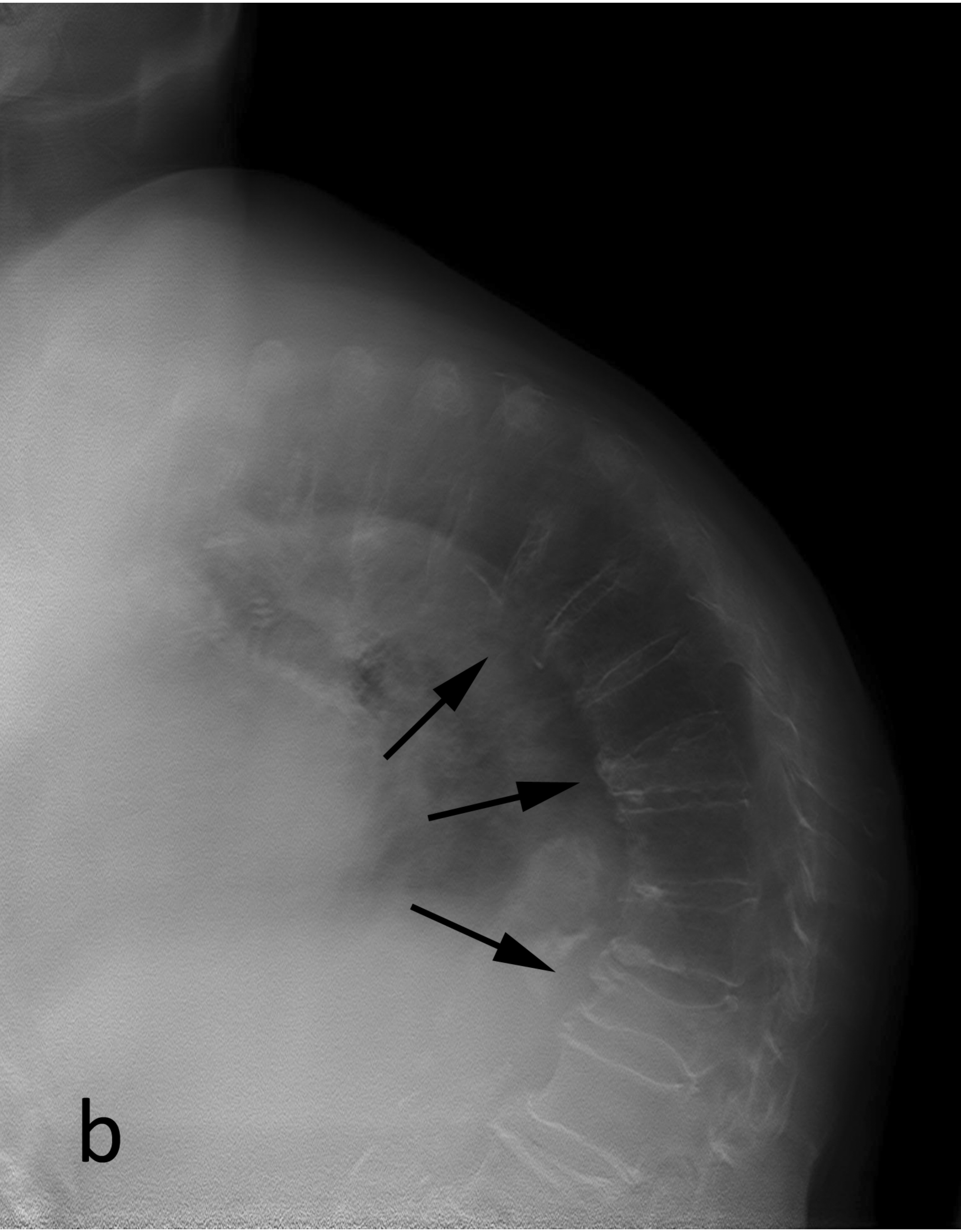

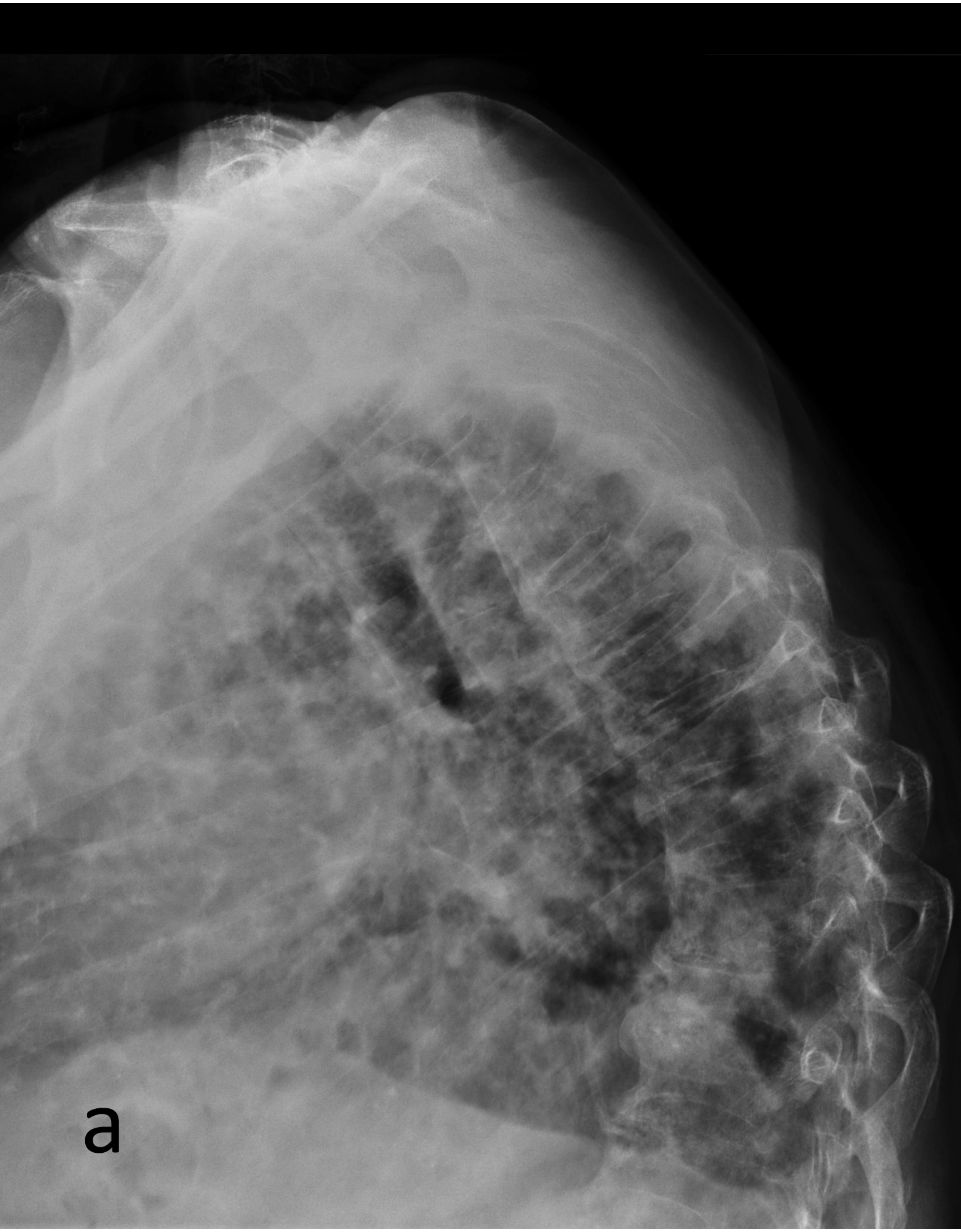
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