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著者	Sasagawa Takeshi, Kunogi Junichi, Masuyama Shigeru, Ogihara Satoshi, Takeuchi Yosuke, Takeshita Yujiro, Fukushima Masayoshi, Kamiya Naokazu, Murakami Hideki, Tsuchiya Hiroyuki
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Title

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Authors

Takeshi Sasagawa, MD[1)], Junichi Kunogi, MD[1)], Shigeru Masuyama, MD[1)], Satoshi Ogihara, MD[1)], Yosuke Takeuchi, MD[1)], Yujiro Takeshita, MD[1)], Masayoshi Fukushima, MD[1)], Naokazu Kamiya[2)] , Hideki Murakami, MD[3)], Hiroyuki Tsuchiya, MD[3)]

Institutes

1) Department of Spine and Orthopedics Surgery / Spine Center , Japanese Red Cross Medical Center

2) FUJIFILM Corporation

3) Department of Orthopaedic Surgery, Kanazawa University

Corresponding Author

Takeshi Sasagawa, MD

Department of Spine and Orthopedics Surgery / Spine Center , Japanese Red Cross Medical Center 4-1-22 Hiroo, Shibuyaku, Tokyo, 150-8935, Japan

Phone: +81-3-3400-1311, Fax: +81-3-3409-1604

E-mail: sasagawawagasasa@yahoo.co.jp

Running title: Image processing for spine X-ray

Abstract

Background. The interpretation of thoracic spine x-rays is difficult because these images cannot clearly visualize the thoracic spine due to the overlap with soft tissues, such as the heart and pulmonary blood vessels. Thus, to improve the clarity of thoracic spine radiographs using existing radiograph equipment, we have investigated a one-shot energy subtraction method to visualize thoracic spine radiographs. Our objective was to evaluate whether the thoracic spine radiographs generated using this method could visualize the spine more clearly than the corresponding original thoracic spine radiographs.

Methods. This study included 29 patients who underwent thoracic spine radiographs. We used a one-shot energy subtraction method to improve the clarity of thoracic spine radiographs. Image definition was evaluated using vertebrae sampled from each region of the thoracic spine. Specifically, these were: Th1,Th5,Th9, and Th12. Image definition was assessed using a three-point grading system. The conventional and processed computed radiographs (both frontal and lateral views) of all 29 study patients were evaluated by 5 spine surgeons.

Results. In all thoracic regions on both frontal and lateral views, the processed images showed statistically significantly better clarity than the corresponding conventional images, especially at all sampling sites on frontal view and T5,9 on lateral view.

Conclusions. Thoracic spine radiographs generated using this method visualized the spine more clearly than the corresponding original thoracic spine radiographs. The greatest advantages of this image processing technique were its ability to clearly depict the whole thoracic spine on frontal views and the middle thoracic spine on the lateral views.

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Introduction

For patients who are suspected of having thoracic spine disorders, thoracic spine radiographs are typically used to evaluate these disorders. However, the interpretation of thoracic spine radiographs is difficult because these images cannot clearly visualize the thoracic spine due to the overlap with soft tissues, such as the heart and pulmonary blood vessels. Thus, to improve the clarity of thoracic spine radiographs using existing radiograph equipment, we have investigated a one-shot energy subtraction method to more clearly visualize thoracic spine radiographs.

This one-shot energy subtraction method [1-4], which has already been effectively used in chest radiography, is one of several image processing technologies. The one-shot energy subtraction method is a unique kind of image processing. Using the energy absorption characteristics differences between bones and soft tissues in the chest, bone images and soft tissue images are visualized separately [1]. The one-shot energy subtraction method has already been effectively used for a wide range of clinical applications with chest images comprised of soft tissue only [2-4].

In contrast, in present study we generated radiographs consisting of only bone signals using this method. Although the one-shot energy subtraction method for bone images has already been effectively used for clearly visualizing rib bones on chest radiographs [2-4], it has not yet been applied to thoracic spine imaging. The purpose of this study was to evaluate whether thoracic spine radiographs generated using this processing could more clearly visualize the spine than the corresponding original thoracic spine radiographs.

Materials and Methods

Patients and X-ray Imageing

This study included 29 patients, 16 men and 13 women, whose mean age was 64 years (range: 13-89 years). These patients who were seen in the clinic because of back pain and underwent thoracic spine radiographs for the examination of thoracic spinal disorders from May 2010 to January 2011. This study was approved by our institutional review board. This study population included 8 women aged 70 years or older. All patients underwent two-way thoracic spine x-ray examinations, which included both frontal and lateral views. We used FCR XU-D1 (Fujifilm Corporation, Tokyo, Japan) as the image reader. The radiographic conditions used are described in Table 1. Two sets of images were prepared from each radiograph: conventional computed radiography (CR) images using conventional processing parameters and processed CR images using the one-shot energy subtraction method that we developed.

X-ray Evaluations

X-ray image definitions were evaluated using vertebrae sampled from each region of the thoracic spine: Th1 from the upper thoracic spine, Th5 and Th9 from the middle thoracic spine: and Th12 from the lower thoracic spine. Image definition was assessed using a three-point grading system: G1 - all of the endplates of the vertebra were not identifiable; G2 - the endplates were identifiable, but bone trabeculae were not identifiable; G3 - both of the endplates and bone trabeculae were identifiable.

The conventional and processed CR images, including both frontal and lateral views, of all 29 study patients were evaluated by the 5 spine surgeons at our hospital: there were a total of 145 evaluations. The evaluating surgeons were blinded regarding the category of the images they evaluated: conventional or processed.

Statistical Analysis

The image evaluations were statistically compared using the Wilcoxon rank-sum test, with statistical significance set at $p < .05$. Inter- and intra-observer reliability were assessed using the Fleiss κ value.

Results

The radiographic diagnosis of these patients was as follows: spondylosis (n=10), normal (n=9), osteoporotic compression fracture (n=6), spondylosis and ossification of yellow ligament (n=2), ossification of anterior longitudinal ligament (n=2).

Table 2 shows the grade distributions among the 145 images evaluated at each of the sampling sites. For all sampling sites on both frontal and lateral views, the processed images had statistically significantly higher grades than the corresponding conventional images. However, for Th1 and Th12 on lateral views, even though the processed images had statistically significantly higher grades than the corresponding conventional images, the number of G3 of the processed images was smaller and the number of G1 images was larger compared with those of the other sampling sites. This indicated that although the lateral views of the upper and lower thoracic spine images processed by this method did show more clarity compared with conventional images, this region did not show as much improvement as with other regions.

An analysis of inter- and intra-observer reliability showed that this assessment measure was reliable (κ=0.65 and 0.82 respectively). Figure 1 for a non-osteoporotic patient illustrates the differences in clarity on both frontal and lateral views between conventional and processed images. This tendency for processed images to show greater clarity than conventional images was also observed for osteoporotic patients (Figure 2). It is worth noting that some lesions that were not clearly detected on conventional images were clearly detected on the processed images (Figures 3, 4).

Discussion

Computed radiography (CR) imaging has become widely used in recent years. CR images differ from conventional film screen images and have many advantages. The greatest advantage is that, unlike conventional film screen images, image processing can be applied to CR images, which can then be modified for a variety of purposes [5]. Because of this characteristic, there have been high expectations for their clinical applications.

One method used for image processing is the energy subtraction method [1]. This involves acquiring images at two different x-ray energies: high-voltage images and low-voltage images. Weighted subtraction is applied to the information from these images to eliminate materials with specific X-ray absorption properties. That is, a high-energy image and a low-energy image are taken for the same subject. Bones and soft tissues have different X-ray absorption magnitude ratios, and the information from these areas is weighted appropriately. Subsequently, signals corresponding to bones or soft tissues can be eliminated by weighted subtraction. Therefore, this method generally requires two images.

Currently, there are two types of energy subtraction methods that are used. One is a one-shot energy subtraction method that obtains two images from one X-irradiation and the other one is a two-shot energy subtraction method that obtains two images from two X-irradiations. Because of artifacts, it is difficult to obtain high quality images of areas with structures that exhibit motion with the two-shot energy subtraction method, such as the great vessels, pulmonary vessels, and the diaphragm [4]. Therefore, in this study we chose a one-shot energy subtraction method.

This method uses two imaging plates that sandwich a metallic filter that absorbs low energy x-ray photons. Low energy information is obtained from the imaging plate in front of a copper plate. High energy information is obtained from the imaging plate in back of the copper plate, as the metal filters out the low energy information [1-4].

A one-shot energy subtraction method has other advantages. One-shot energy subtraction involves using the same level of radiation exposure as that for conventional CR imaging. Furthermore, this image processing technology is available for existing x-ray equipment. There is no additional work load for the technologist because of the one shot technology, which provides the same workflow as regular CR operation. The image processing and its optimization are automatically done without any additional interruption. This method has already been applied clinically to chest radiography. Its reported utility was reported mainly for creating images of soft tissue structures after bone structures were removed.

In this study, we applied one-shot energy subtraction to plain radiographs of the thoracic spine. For frontal views, this image processing produced clear images of the whole thoracic spine. In particular, images of the upper thoracic spine typically have poor clarity because this area overlaps with the trachea in which air appears as black. In this study, energy subtraction reduced this effect of air and produced clearer images. For lateral views, this method produced clear images of the middle thoracic spine. Possible reasons for these results are the following. The thoracic spine tends to be poorly visualized due to the overlap by the lung, pulmonary vessels, heart, aorta, and trachea, which makes the spine look white or black. Energy subtraction eliminates these soft tissue obstructions and the whole thoracic spine is visualized when it is brought into the adequate density range.

Similarly, by narrowing the density range of the whole thoracic spine, it is possible to produce a high contrast for the whole image without producing white and black areas. As a result, parts that are invisible due to low contrast become high in contrast. Thus, the whole spine on a frontal view and the middle thoracic spine on a lateral view were depicted more clearly using a one-shot energy subtraction method.

In contrast, lateral views of the upper and lower thoracic spine became less clear than for other sampling sites, even after these images were processed using this method. The upper thoracic spine overlaps not with soft tissue structures, but with bone structures, such as the head of the humerus and the scapula. The lower thoracic spine overlaps with the diaphragm, which has thicker soft tissue than the heart and pulmonary vessels. These parts of the thoracic spine have low x-ray transmissions and low energy components of the x-ray beam are mostly absorbed. Thus, x-rays transmitted through a subject have almost no low-energy components, just as with signals of the thoracic spine, especially when one wants to image the upper thoracic spine. The difference in energy between two imaging plates becomes small. Therefore, it is likely that accuracy declines when attempting to depict of the thoracic spine.

For plain x-ray imaging of the thoracic spine, this study showed that the greatest advantages of this image processing method were the clarity of the frontal views of the thoracic spine and the lateral views of the middle spine. In some cases, this image processing enabled the clear depiction of lesions, which could not be clearly visualized using conventional images. These results suggest the utility of this method in clinical settings. Because many cases in this study did not have abnormal lesion and various disorders, such as ossification of the posterior longitudinal ligament, tumor and infection of the thoracic spine were not included in this study, further study is necessary to examine the utility of this method in diagnosing these conditions.

Conclusion

The thoracic spine x-ray images generated using a one-shot energy subtraction method visualize the spine more clearly than the corresponding original thoracic spine x-ray images. The greatest advantages of this image processing are the ability to clearly depict the whole thoracic spine on the frontal views and the middle thoracic spine on the lateral views. Although lateral views of the upper and lower thoracic spine images processed by this method also showed more clarity compared with conventional images, this region did not show as much improvement as with other regions.

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Figure legends

Figure 1.

Radiographs for a non-osteoporotic patient

A: Conventional image (frontal view), B: processed image (frontal view), C: conventional image (lateral view), D: processed image (lateral view)

Figure 2.

Radiographs for a patient with osteoporosis (81-year-old female)

A: Conventional image (frontal view), B: processed image (frontal view), C: conventional image (lateral view), D: processed image (lateral view)

Figure 3.

Radiographs for a patient with ossification of anterior longitudinal ligament (OALL)

OALL, which are not clearly detected on a conventional image, are clearly detected on a processed image.

A: Conventional image (lateral view), B: processed image (lateral view)

Figure 4.

Radiographs for a patient with ossification of yellow ligaments (OYL).

OYL, which are not clearly detected on a conventional image, are clearly detected on a processed image.

A: Conventional image (lateral view), B: processed image (lateral view)

C: enlarged view (conventional image), D: enlarged view (processed image)

E: corresponding CT image

Table 1. X-ray imaging parameters

	Electric voltage	Electric current	Time	Distance
Frontal view	75 kV	200 mA	0.2 sec	100 cm
Lateral view	80 kV	250 mA	0.25 sec	100 cm

Table 2. Grading comparisons between conventional and processed images

	Conventional			Processed			P value
	G1	G2	G3	G1	G2	G3	
Frontal view							
T1	8	117	20	1	6	138	< .05
T5	43	95	7	15	27	103	< .05
T9	4	137	4	1	37	107	< .05
T12	5	135	5	0	65	80	< .05
Lateral view							
T1	133	12	0	111	31	3	< .05
T5	8	127	10	0	21	124	< .05
T9	1	130	14	0	4	141	< .05
T12	22	118	5	22	60	63	< .05

Fig 1.

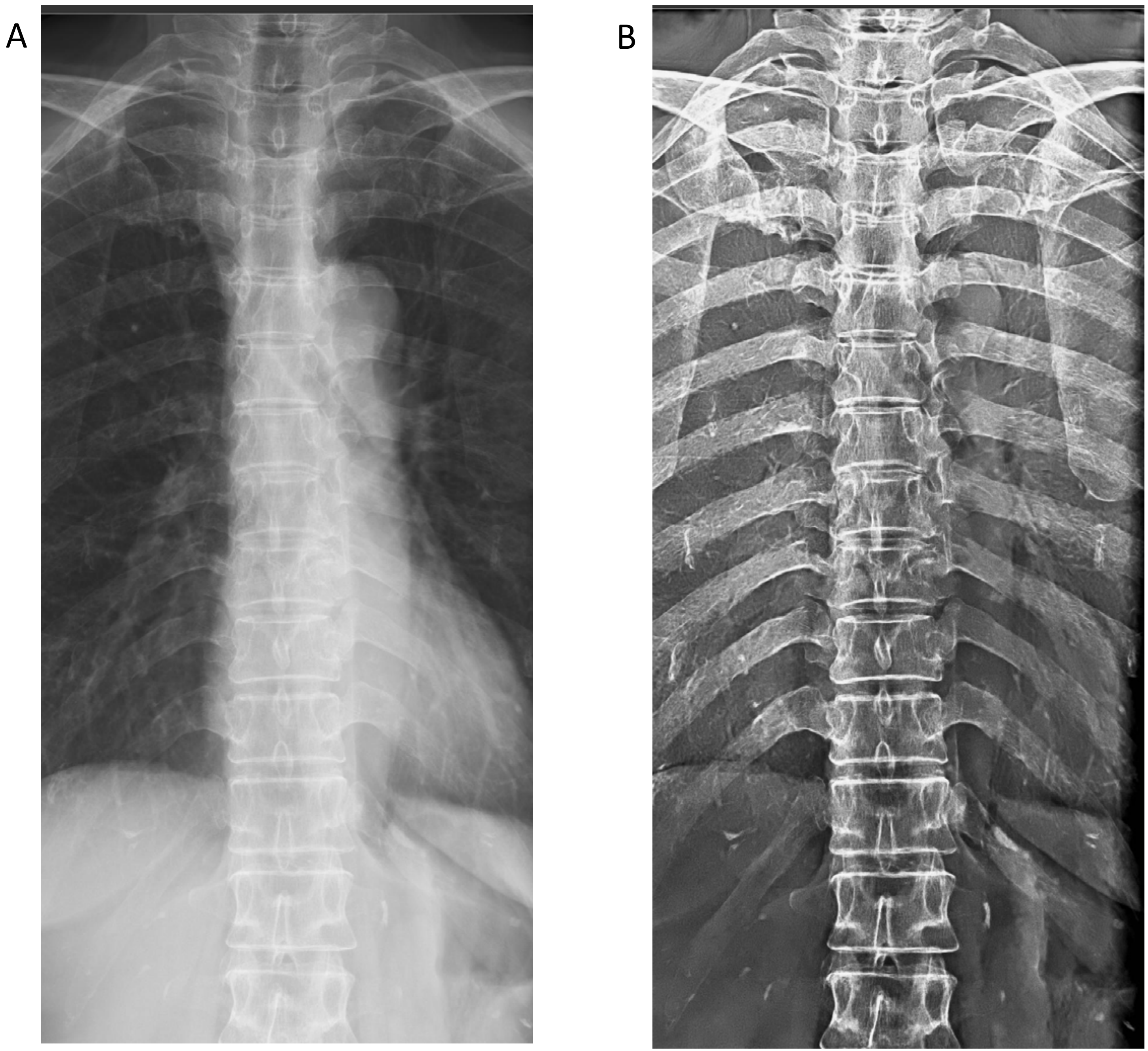

Fig 1.

C

D

Fig 2.

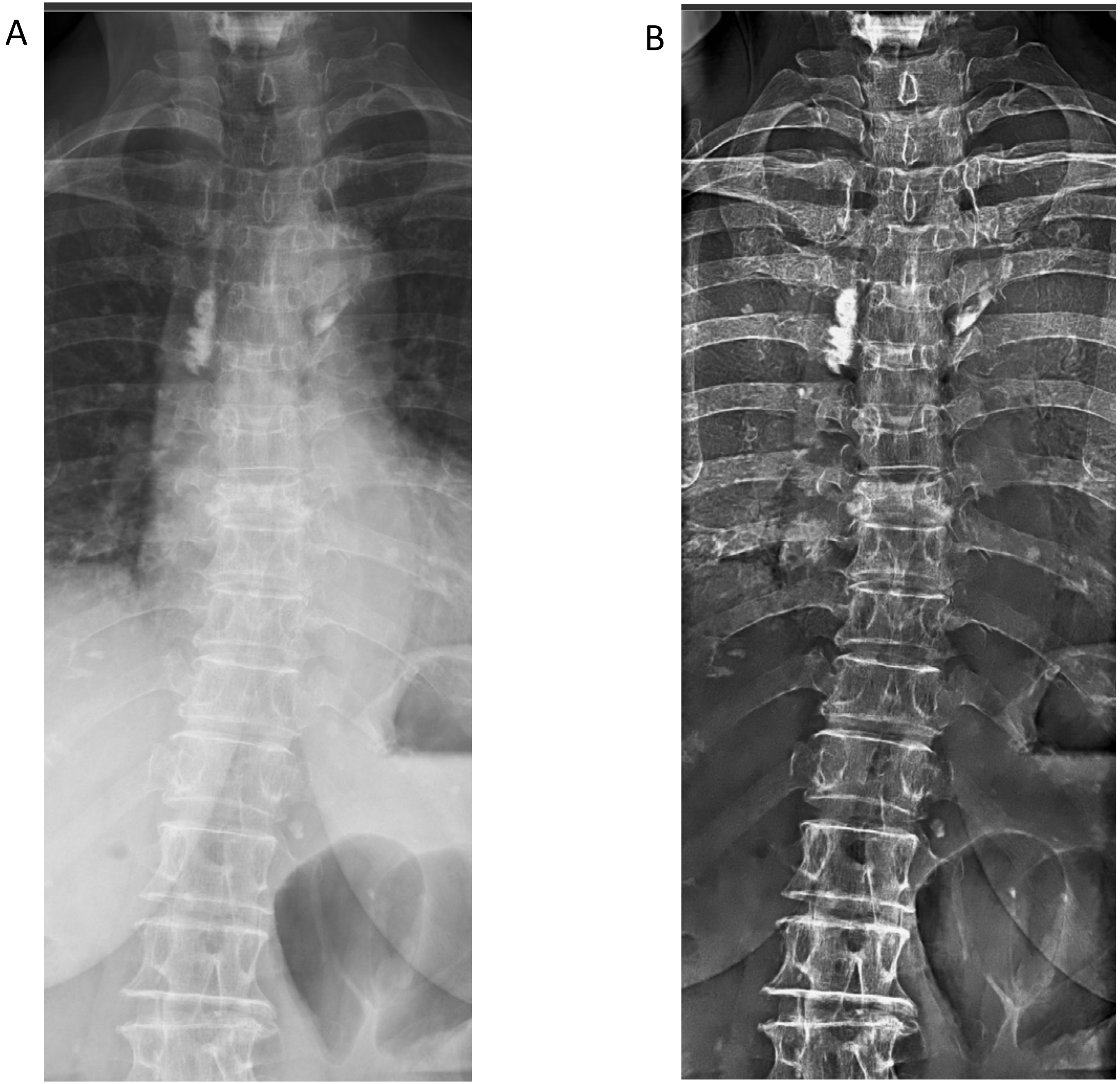

Fig 2.

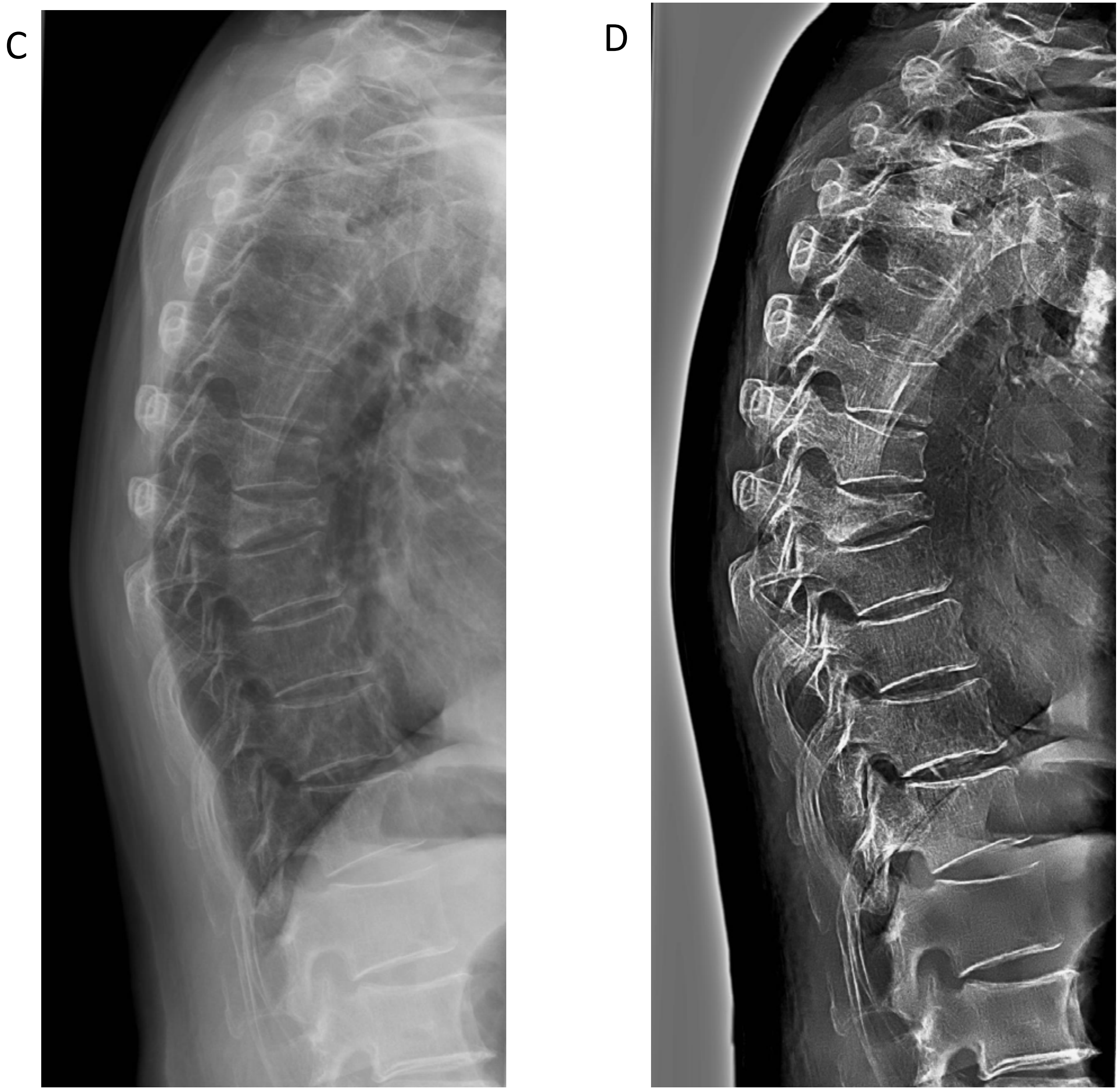

Fig 3.

A

B

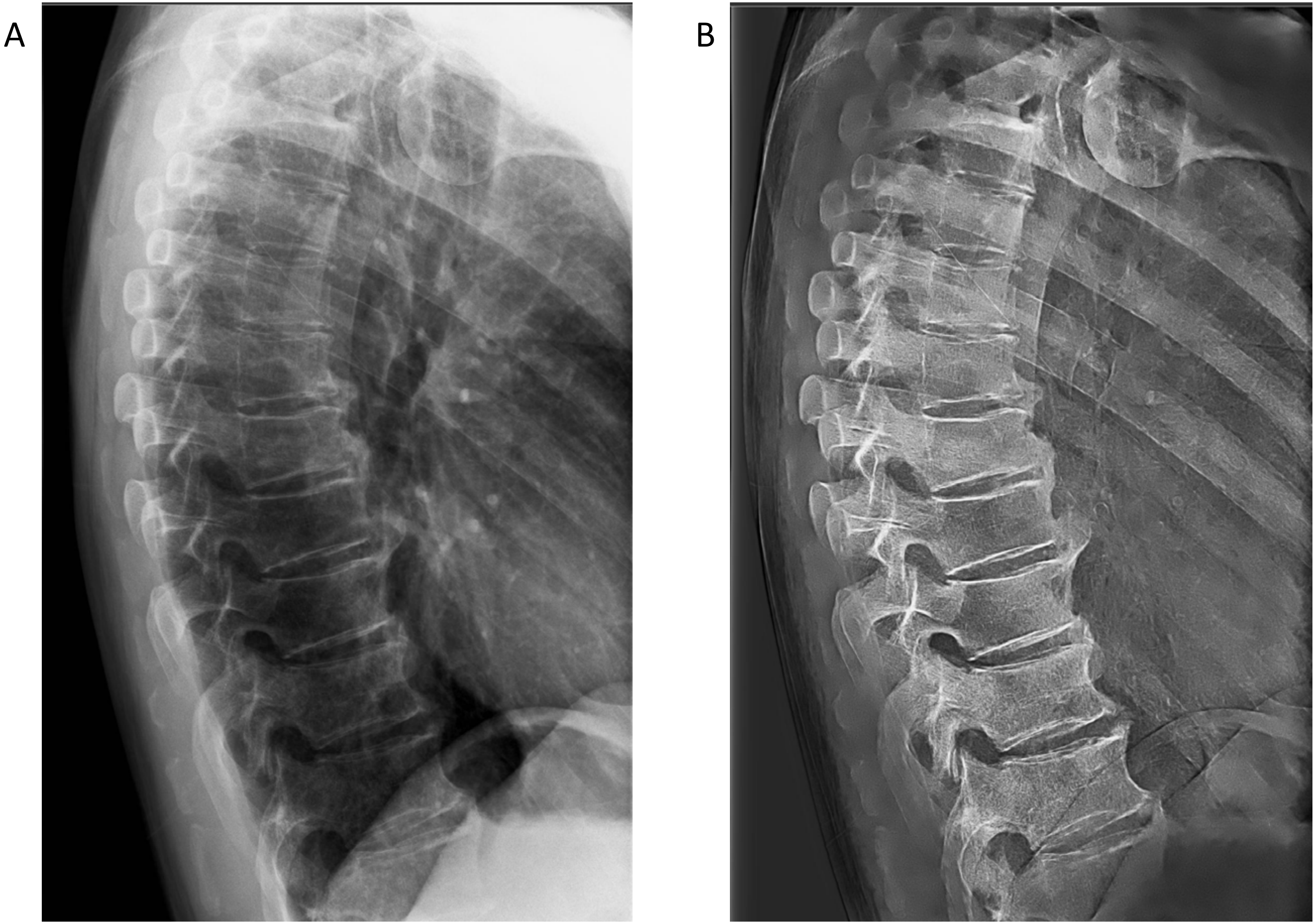

Fig 4.

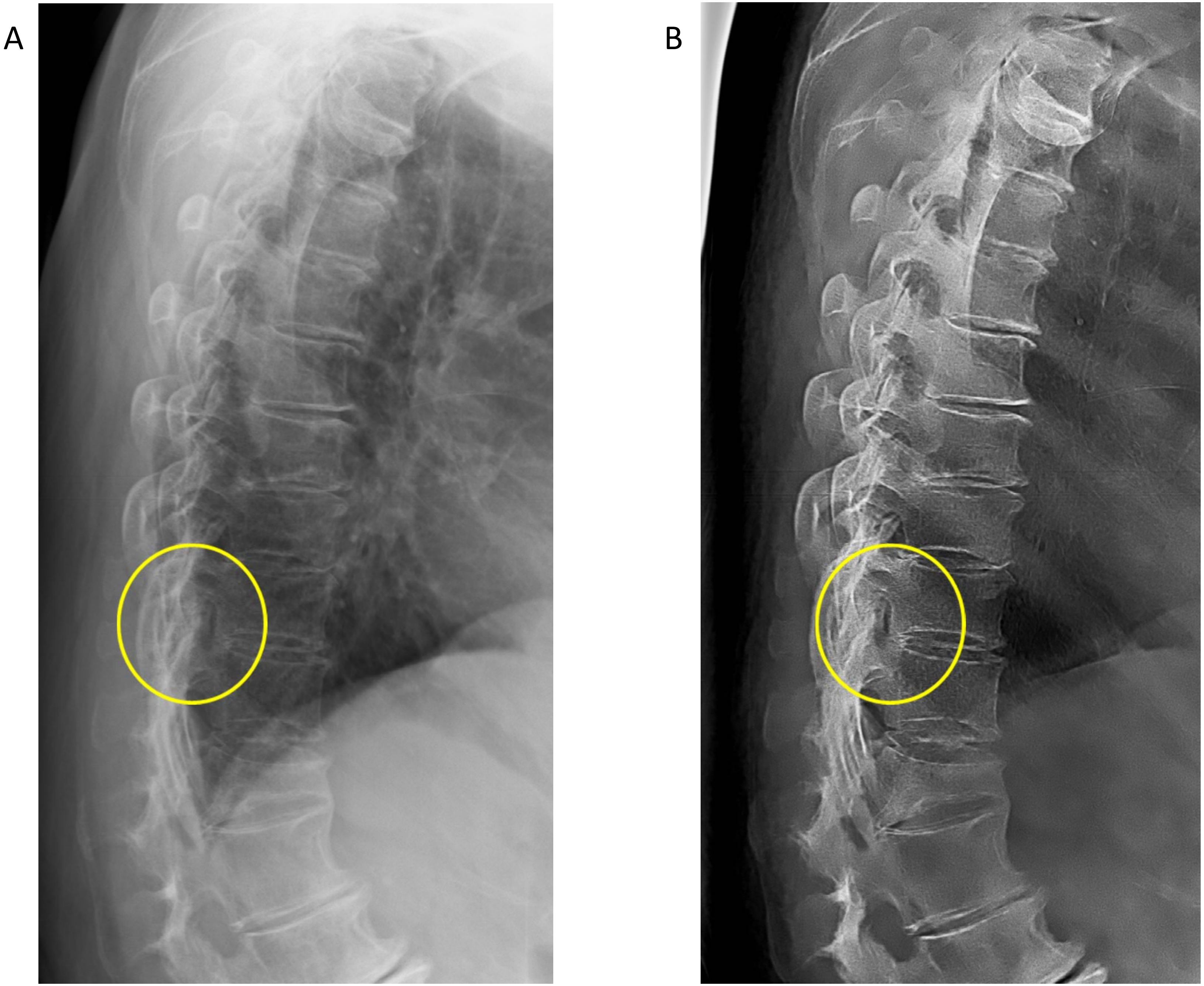

Fig 4.