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Thoracic spine X-ray examination of patients with back pain using different breathing technique and exposure times – A diagnostic study

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ABSTRACT

Introduction: The breathing and suspended inspiration techniques are often used interchangeably for spine X-ray examinations. However, these techniques are not always adequately supported by clinical evidence.

This study aimed to determine the two techniques' diagnostic value and adverse image outcomes.

Methods: A total of 400 participants were examined on a Siemens Ysio Max system and randomized into four examination groups: suspended inspiration or breathing techniques with exposure times of 1, 2, and 3.2 s, respectively. Two consultant radiologists conducted the evaluation of the X-ray images. If disagreement was present, the radiologists collaboratively reviewed the X-ray images until a consensus was reached.

Results: The final 394 study population comprised 275 women and 119 men with a mean age of 64 years (range:18–96 years). The proportions of visually sharp reproduction of the endplates and trabecular structures did not differ significantly with regards to differences in exposure times between groups. The breathing technique groups had significantly higher proportions of blurring and motion artifacts ($p < 0.001$).

However, adverse image outcomes (motions artifacts) were significantly lower in the 1-s exposure group.

Conclusions: The suspended inspiration and breathing techniques performed equally well regarding visually sharp reproduction. However, the suspended inspiration technique was superior to the breathing technique.

regarding adverse image outcomes, although the latter could be improved by using a shorter exposure time.

Implications for practice: The suspended inspiration and breathing technique appeared to perform at equal diagnostic levels. The suspended inspiration technique should be preferred due to its reduced risk of adverse image outcomes. However, the risk could also be reduced using a short exposure time with the breathing technique.

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Introduction

Back pain is a common complaint in the general population, but particularly among patients with osteoporosis and spine degeneration. The number of patients with those ailments is increasing with population aging. In 2010, it was estimated that 22 million women and 5.5 million men in Europe had osteoporosis according to the World Health Organization criteria and that 20 % of all men and 33 % of all women will experience an osteoporotic fracture during their lifetime.[1] Osteoporotic fractures are commonly localized to the thoracolumbar or lumbar spine and contribute to deteriorated quality of life and increased mortality.[2,3]

The typical clinical presentation of osteoporotic spine fractures is the sudden onset of back pain, but not necessarily associated with the involvement of any trauma mechanism. Patients are then referred for radiographic X-ray examination of the spine by their general practitioner due to the sudden onset of pain combined with a clinical suspicion of compression fractures, degenerative changes, and suspicion of spondyloarthropathy.[4–6] This low-cost radiology procedure is relatively simple to perform. Two different radiographic views are used to examine the spine: anterior-posterior (AP) and lateral. The AP view allows the clinician to assess any coronal deformity, such as scoliosis, changes in the intervertebral joint spaces, and costovertebral joints.[7-] It is possible to evaluate all 12 thoracic vertebrae in the AP. The lateral view allows the clinician to assess the endplates, the anterior and posterior edges of the vertebral bodies, the intervertebral joint spaces, the facet joints, and the posterior elements. However, it is difficult to visualize the upper thoracic vertebrae T1-T3 on the lateral view due to the high mass of the patient in the upper thoracic area. The different types of soft tissue surrounding the spine and the air-filled lungs may cause underexposure of the upper thoracic T1-T3 vertebrae, and the shoulders may limit the evaluation. Underexposure of the inferior vertebrae in the lower thoracic spine occurs due to the abdominal tissue. The lower thoracic spine is the primary location of spinal compression fractures and Gehlbach et al. reported that the false negative rate for detecting spinal fractures is as high as 45 %.[7] Bariatric patients may pose some challenges when positioned for spine images. The increased density of adipose tissue may require an increase in technical factors, such as an increase in kilovoltage peak (kVp), to improve penetration through the additional soft tissue.[8,9]

Lampignano et al. described that thoracic spine X-rays could be performed with suspended respiration or breathing.[8,9] The first technique was *suspended inspiration*, in which the patient is instructed to inhale and hold their breath while using automatic exposure control (AEC). It is crucial to place the center of the AEC in the middle of the vertebrae to obtain correct exposure. Lampignano et al. also described the *breathing technique*,[8,9] in which the patient is required to breathe gently during the exposure with a minimum exposure time of 3–4 s, or 2–4 s as more recently recommended, in a low milliampere (mA) setting.[9] The radiographer must ensure that the thoracic spine does not move during the examination and that the thoracic ribcage moves only slightly during gentle breathing. This examination technique requires the patient to follow instructions, which can be challenging if respiration causes discomfort or pain. The breathing technique causes blurring of the soft tissue, ribs, and lung markings, aiming to better visualize the lateral examination of the vertebrae. If the patient cannot cooperate by standing still and only breathe without swaying, unwanted motion artifacts of the spine may occur, causing inadequate evaluation of the spine's anterior and posterior elements.[8,9]

To our knowledge, no previous studies have focused on the problems associated with overlying lung tissue or investigated the ideal exposure time for the lateral spine radiograph. Therefore, this study aimed to compare the image quality of the lateral thoracic spine X-ray examination with the suspended inspiration or breathing technique using different exposure times.

Methods

Study setting

This diagnostic study was conducted in the Department of Radiology at the North Denmark Regional Hospital in Frederikshavn, Denmark, between August 1, 2017, and July 31, 2018. This department serves a population of 58,000 inhabitants and currently employs 25 radiographers who perform 400–600 thoracic spine X-ray examinations annually. The suspended inspiration technique was performed routinely in the department before this study.

Pilot study

A pilot study was performed with 40 participants to ensure whether participants could follow the breathing technique instructions. It used three different exposure times, based on technical possibilities and the recommendations in the existing literature by Lampignano et al.[8,9] The maximum possible exposure time was 3.2 s due to the limitations of the Siemens Ysio Max system (version VE10Q; Siemens AG, Muenchen, Germany). Lampignano et al. recommended a minimum exposure time of 2 s.[8,9] An exposure time of 1 s represents a short exposure time and was chosen randomly. Rather than using AEC for the suspended inspiration technique group for the study, free exposure with fixed kVp and mAs dependent on the patient BMI was used. Furthermore, the two radiographers performing the examinations coordinated their communication of the respiration instructions to the participants to ensure that each was given the same instructions.

Diagnostic study

The diagnostic study included 400 participants for lateral X-ray examination of the thoracic spine. Its inclusion criteria were participants aged $\geq$18 years referred for thoracic spine X-ray examination who could cooperate and understand the radiographer's instructions for the suspended inspiration or breathing technique. Participants aged 18–35 years should be able to undergo the examination in the erect position. Participants with spinal implants were excluded from this study. Each participant was randomized into one of four X-ray examination groups using Research Electronic Data Capture (REDCap)[10,11]: (1) suspended inspiration with free exposure, (2) breathing with a 1-s exposure, (3) breathing with a 2-s exposure, and (4) breathing with a 3.2-s exposure. The breathing technique was performed with gentle expiration after a deep inspiration during the lateral spine examination.

Technical information

The X-rays were performed using a Siemens Ysio Max unit. Total filtration was 2.5 mm Al. A focused grid with a ratio of 13:1 with 92 lines/cm was used and the source-image-distance (SID) was 115 cm. The image detector was a flat panel digital amorphous Silicon (a-SI) detector with a size of 43 cm $\times$ 43 cm and the sensitivity was 400. The image processing parameters were as follows. Gradation parameters: shape = 19, contrast = 1.4, center = 3600, and offset = −200. Spatial frequency parameters: edge filter: kernel = 7 and gain = 0.5; harmonization: kernel = 255 and gain = 0.3.

KVp and mAs were determined manually based on the participant's body mass index (BMI).[12] The exposure parameters were 81 kVp and 28 mAs for participants with a BMI <27.5 kg/m2 and

87.5 kV and 28 mAs for participants with a BMI ≥27.5 kg/m2.[12] In order to decrease scatter, the smallest possible collimation was used.

Participants aged 18–35 years were examined in the erect position, and those aged >35 years were examined in the supine position, per the department's standard operating procedure. The radiographer centered the central beam on the inferior angle of the scapula and the arms were raised to remove them from the direct X-ray beam path, minimizing the proximal humerus overlying the thoracic vertebrae. If the participant had scoliosis, the convex side of the scoliosis was positioned nearest the detector. Caudal or cephalic tube angulation may be required to achieve true lateral projection. Radiographic criteria for a lateral thoracic spine were described so that all T4–T12 vertebrae were well visualized, the intervertebral joint space should be free, and the posterior edge of the corpora should be projected with no rotation.[13] Study data (date, sex, age, height, and weight) were collected and managed using REDCap.

All 400 participants had examinations performed by two experienced radiographers, randomly determined by whichever was on duty. Two consultant radiologists with >15 and > 30 years of experience independently assessed the X-ray images. The consultant radiologists utilized both the same workstation standardized according to ACR-AAPM-SIIM technical standard[14] during the entire of the study. The evaluations were conducted in a controlled environment with stable lighting conditions to minimize variables. All X-ray images were viewed on EasyViz diagnostic viewer,[15] and no modifications were made to the image features during the assessment process, including brightness, contrast, and size. Both consultant radiologists assessed each X-ray image based on four predetermined evaluation criteria: (A) visually sharp reproduction of endplates (B) visually sharp reproduction of trabecular structures, (C) blurring in the basic lung segments (Th4–Th12), and (D) motion artifacts in the column. These criteria were selected to encompass both diagnostic aspects, represented by criterion (A) and (B) and technical aspects, represented by criterion (C) and (D). For diagnostic evaluation, criterion (A) and (B) were chosen to accurately visualize the structures primarily affected by osteoporotic and degenerative changes.[16,17] The clear visual reproduction of endplates and trabecular structures served as reliable indicators for diagnosing these conditions.[18–21] The consultant radiologist evaluated whether these elements where sharply visualized or not. In terms of technical criteria, the selection process was focused on evaluating the impact of the breathing method and exposure times on image quality. The presence of motion artifact in the column and blurring in the basic lung segments were considered particularly relevant, as they are directly influenced by these factors and can be easily assessed. In addition, criterion (C) was chosen as an indicator of participant's understanding and adherence to the radiographer's instructions. Since assessing these criteria only required a simple 'yes' or ‘no’ response rather than relying on specialized technical knowledge, it was carried out by the two consultant radiologists. If disagreement was present, the two consultant radiologists collaboratively reviewed the X-ray images until a consensus was reached. They independently recorded their respective findings from each assessment into REDCap. The consultant radiologists remained blinded to the participant groups throughout the entire study period. No training session of the two consultant radiologists was conducted prior to the study.

Ethical considerations

Ethical approval was deemed unnecessary due to the quality development nature of this diagnostic study. This diagnostic study was registered at the North Denmark Region research project administration unit and the Danish Data Protection Authority (ID: 2016–168).

Statistical analysis

Since the data were not normally distributed, continuous variables are presented as medians and interquartile ranges. Categorical variables are presented as counts and proportions. Confidence intervals (CIs) were calculated using a binomial distribution for each quality criteria proportion within each examination technique group. Quality criteria proportions were visualized as point estimates and error bars expressing the 95 % CIs. Proportions were compared using Fisher's exact test, and continuous variables were compared using Wilcoxon's rank sum test. Further evaluation of exposure time with the breathing technique included blurring in the basic lung segment and motion artifacts in the column. Risk differences for these outcomes were calculated using a Gaussian general linear model with identity as the link function. CIs were adjusted using robust variance estimation.[22] A 1-s exposure time was used as the reference group. The model was adjusted for age (categorical: age ≥35 years), BMI (categorical: BMI <27.5 kg/m^2), and whether the participant was examined in the erect position. The interaction between the two breathing techniques and whether the participant was examined in the erect position was determined. All analyses were conducted in the R statistical software (version 3.6.1), with a two-sided *p*-value <0.05 considered statistically significant.

Results

Study population

Thoracic spine X-ray images for 394 out of 400 planned participants were eligible for evaluation. Two participants were missing from the evaluation, and four participants were excluded from participating in the study since TH12 was not fully visualized in two participants and scoliosis disrupted the intervertebral joint spaces in other two participants examinations. The overall study group comprised 119 men (30.2 %) and 275 women (69.8 %) with a mean age of 64 years (range: 18–96 years, standard deviation: 17.1; Table 1). Demographic characteristics did not differ significantly among the four study groups examined.

Initial separate evaluation by consultant radiologists

The two consultant radiologists’ initial evaluations of the X-ray images showed 67 % agreement for the criterion “visually sharp reproduction of the endplates” and 59 % agreement for the criterion “visually sharp reproduction of the trabecular structures.” Consensus was reached in all evaluations.

Overall comparison

The counts and proportions of agreement across the four examination technique groups are shown in Table 2. The proportions of X-ray images with visually sharp reproduction of the endplates and trabecular structures did not differ significantly between the four groups (p = 0.4571 and p = 0.6731 respectively). The breathing technique groups generally had higher proportions of visually sharp reproduction of the endplates than the suspended inspiration group (Fig. 1), although the difference was non-significant (p = 0.1225). In contrast, the proportion of visually sharp reproduction of trabecular structures was higher in the suspended inspiration technique group than in the breathing technique

Table 1
Participant demographic characteristics in accordance with the different x-ray examination techniques.

	Total		Breathing technique		
	Total N = 394	Suspended inspiration technique n = 99	Exposure time 1 s. n = 100	Exposure time 2 s. n = 98	Exposure time 3.2 s. n = 97
Gender, n (%)					
Female	275 (69.8)	65 (65.7)	73 (73.0)	73 (74.5)	64 (66.0)
Male	119 (30.2)	34 (34.3)	27 (27.0)	25 (25.5)	33 (34.0)
Age (years), n (%)					
<65	190 (48.2)	47 (47.5)	49 (49.0)	42 (42.9)	52 (53.6)
≥65	204 (51.8)	52 (52.5)	51 (51.0)	56 (57.1)	45 (46.4)
median [IQR]	65 [52, 77]	65 [53, 75]	66 [54.8, 76.2]	69.5 [54.2, 81.0]	64 [52, 74]
Body Mass Index, n (%)					
<27.5	262 (66.5)	71 (71.7)	65 (65.0)	58 (59.2)	68 (70.1)
≥27.5	132 (33.5)	28 (28.3)	35 (35.0)	40 (40.8)	29 (29.9)
median [IQR]	25.7 [22.9, 28.8]	25.5 [22.3, 28.5]	25.4 [22.9, 28.8]	25.8 [23.4, 29.4]	25.5 [22.5, 28.5]
Position					
Supine	369 (93.7)	93 (93.9)	93 (93.0)	91 (92.9)	92 (94.8)
Erect	25 (6.3)	6 (6.1)	7 (7.0)	7 (7.1)	5 (5.2)

IQR: Inter Quartile Range.

Table 2
Results of the four quality criteria being evaluated in accordance with the different x-ray examination techniques.

			Breathing technique			
	Total N = 394	Suspended inspiration technique n = 99	Exposure time 1 s. n = 100	Exposure time 2 s. n = 98	Exposure time 3.2 s. n = 97	P-value
	n (%)	% [95%CI]	% [95%CI]	% [95%CI]	% [95%CI]	
Visually sharp reproduction of endplates	283 (71.8)	65.66 [55.88; 74.27]	74.00 [64.63; 81.60]	72.45 [62.88; 80.32]	75.26 [65.82; 82.77]	0.4571
Visually sharp reproduction of trabecular structures	168 (42.6)	47.47 [37.92; 57.22]	43.00 [33.73; 52.78]	40.82 [31.61; 50.71]	39.18 [30.05; 49.12]	0.6731
Blurring in the basic lung segment (Th4–Th12)	264 (67.0)	1.01 [0.18; 5.50]	82.00 [73.33; 88.30]	89.80 [82.23; 94.36]	95.88 [89.87; 98.38]	<0.001
Motion artifacts of the column	109 (27.7)	1.01 [0.18; 5.50]	20.00 [13.34; 28.88]	41.84 [32.56; 51.73]	48.45 [38.76; 58.27]	<0.001

groups, although the difference was also non-significant (p = 0.2910) (Table 2). Only 1 % of the participants in the suspended inspiration group showed blurring in the basic lung segment and motion artifacts of the column (Table 2). The breathing technique groups had significantly higher prevalence of blurring and motion artifacts ($p < 0.001$).

The risk of blurring in the basic lung segment according to breathing technique and exposure time was 14 % (95 % CI: 6%–23 %) lower for participants with a 1-s exposure time than a 3.2-s exposure time (adjusted model). No significant difference was found between the 2-s and 1-s exposure times (Table 3). All adjusted models showed no interaction between exposure time and erect position.

The further exploration of motion artifacts of the column with exposure time for the breathing technique showed that participants with the 1-s exposure time had a 21 % (95 % CI: 9%–34 %) and 29 % (95 % CI: 17%–42 %) lower risk of motion artifacts than participants with a one- or 3.2-s exposure time, respectively (adjusted model; Table 4).

Discussion

In our study, the X-ray image quality appeared comparable in all four groups. The breathing technique did not significantly affect the visualization of the endplates or trabecular structures compared to suspended inspiration (Images 1 and 2). While the results did not reach statistical significance, there was a higher level of "visually sharp reproduction of the endplates" in the breathing technique groups than in the suspended inspiration technique group. The optimal visualization of endplates is essential for diagnosing vertebral fractures, which is a criterion for diagnosing osteoporosis in national guidelines.[23]

We also found a slightly higher proportion of "visually sharp reproduction of the trabecular structures" in the suspended inspiration group than in the breathing technique groups. While the trabecular bone structure appears more visible in patients with osteoporosis, radiographs are not a diagnostic tool for clinically diagnosing osteoporosis. Dual Energy X-ray absorptiometry (DEXA) scans are the gold standard for diagnosing osteoporosis,[23,24] and patients with low-energy spine fractures of the thoracic spine are often referred for a DEXA scan after x-ray examination.

Regarding the breathing technique, participants were instructed to breathe gently during their examination, causing blurring, which was the aim of this study. This phenomenon was already evident with a 1-s exposure, demonstrating that participants could cooperate with the instructions given by the radiographers. While all participants could cooperate with the instructions given in this study, patients with pulmonary or other chronic diseases might benefit from a short exposure time. Only minor motion artifacts of the column were evident in the suspended inspiration group. In contrast, motion artifacts of the column correlated with exposure time in the breathing technique groups, increasing significantly from 20 % with a 1-s exposure to 48.5 % with a 3.2-s exposure ($p < 0.001$). In our study, motion artifacts of the column were present and increased with exposure time.

Our study reported a large interobserver variation for the "visually sharp reproduction of endplates" and "visually sharp reproduction of the trabecular structures" criteria. Since this diagnostic study aimed to improve the image quality, a consensus was reached between the two consultant radiologists evaluating the examinations when disagreement occurred. While previous studies have highlighted the limited diagnostic sensitivity and specificity of the thoracic spine X-ray, it is still preferred as the first diagnostic examination due to its low cost.[16,25,26]

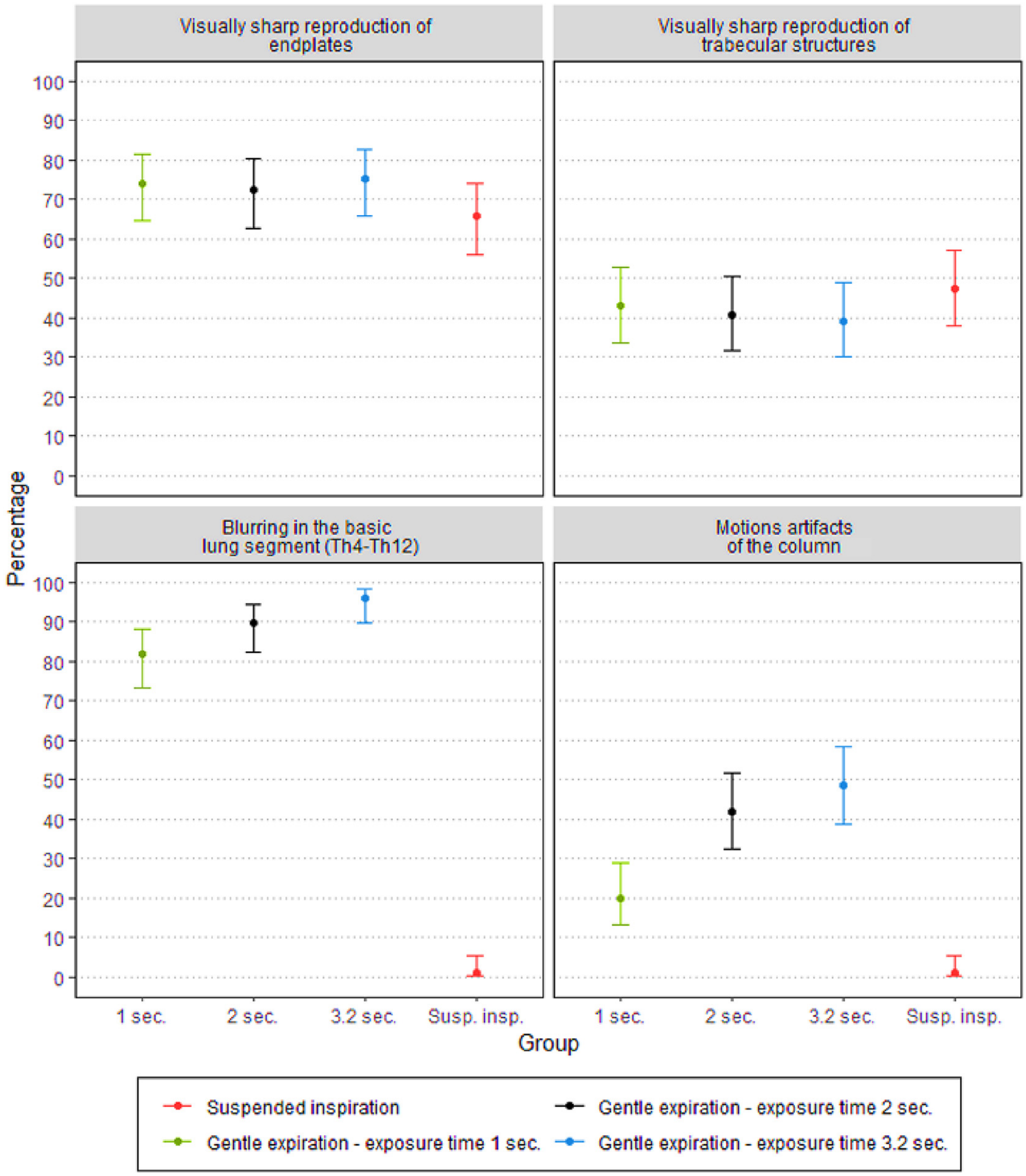

Figure 1. Comparison of the proportions and 95 % confidence intervals of the four criteria by x-ray examination techniques between the study groups.

Our study has a number of limitations. First, it was designed to examine the four chosen subjective image quality criteria: endplates, trabecular structures, blurring and motion artifacts. Our study would have been strengthened if objective measures had been used, such as the vertebral compression ratio[27] and the consultant radiologists evaluated the image quality criteria separately in a double-blinded design. Second, it used the same post-processing for all X-ray images, our department's current standard operating procedure. This approach might change in the future with further improvements in post-processing techniques and thus the possibility of image optimization. Third, as part of our study, we changed our clinical practice from AEC to free exposure to avoid underexposure in the suspended inspiration group and ensure comparable exposures in all four groups. Placing the center of the AEC in the middle of the vertebrae can be challenging due to the curvature of the spine, which might have made previously underexposed X-ray images in the suspended inspiration group appear better in our study. Fourth, the lack of a pre-study training session resulted in a lack of alignment among the consultant radiologists. Consequently, this led to notable discrepancies in the interobserver agreement necessitating the implementation of consensus evaluation. It would have been advantageous to modify the study design to ensure that consultant radiologists were aligned and able to evaluate the image quality criteria separately.

Image 1. Suspended inspiration with fixed kVp and mAs.

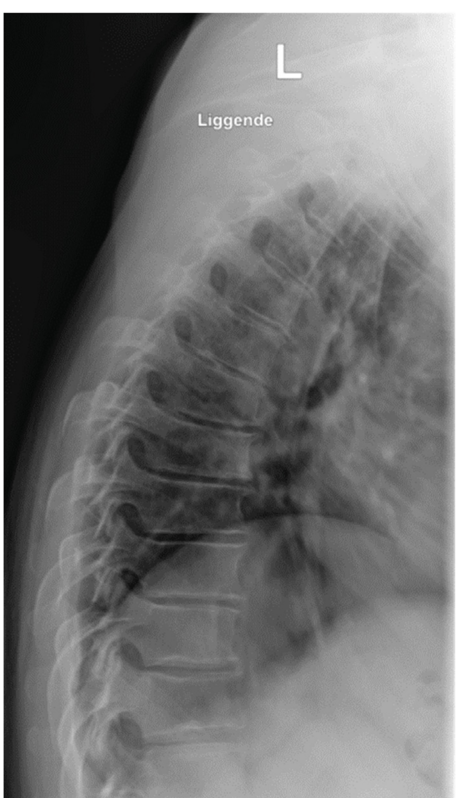

Image 2. Breathing technique with 3.2 s exposure time.

Table 3
Risk of motion artefacts in the x-ray images by un-adjusted and adjusted estimates, respectively, from the linear regression, compared for breathing technique only.

Model		Risk Difference (%)	95 % CI		P-value
Unadjusted	Exposure time 1 s.	Ref.	–	–	–
	Exposure time 2 s.	21.84	9.31	34.36	<0.001
	Exposure time 3.2 s.	28.45	15.79	41.12	<0.001
Adjusted	Exposure time 1 s.	Ref.	–	–	–
	Exposure time 2 s.	21.4	9.26	33.53	<0.001
	Exposure time 3.2 s.	29.46	16.95	41.97	<0.001

The adjusted model included age (categorical: age ≥35 years), BMI (categorical: BMI <27.5) and whether the patient was examined in erect position.
Ref.: Reference; sec.: seconds.

Table 4
Risk of blurring in the basic lung segment in the x-ray images, by un-adjusted and adjusted estimates, respectively, from the linear regression, compared for breathing technique only.

Model		Risk Difference (%)	95 % CI		P-value
Unadjusted	Exposure time 1 s.	Ref.	–	–	–
	Exposure time 2 s.	7.8	−1.83	17.42	0.11235
	Exposure time 3.2 s.	13.88	5.37	22.38	0.00139
Adjusted	Exposure time 1 s.	Ref.	–	–	–
	Exposure time 2 s.	7.26	−2.29	16.82	0.136
	Exposure time 3.2 s.	14.47	5.97	22.97	<0.001

The adjusted model included age (categorical: age ≥35 years), BMI (categorical: BMI <27.5) and whether the patient was examined in erect position. Ref.: Reference; sec.: seconds.

Conclusions

Our study aimed to determine the diagnostic value of the suspended inspiration technique compared to the breathing technique with different exposure times. We found a significantly higher rate of motion artifacts of the column with exposure times >1 s. Therefore, our study does not support the existing literature regarding an exposure time of 2–4 s. The breathing technique did not significantly improve visualization of the vertebral contour, but there was a tendency towards an improved visualization of the endplates. The diagnostic value of the examinations was the same in all groups.

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