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CHEST

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Should 3K zoom function be used for detection of pneumothorax in cesium iodide/amorphous silicon flat-panel detector radiographs presented on 1K-matrix soft copies?

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Abstract The purpose of the study was to evaluate observer performance in the detection of pneumothorax with cesium iodide and amorphous silicon flat-panel detector radiography (CsI/a-Si FDR) presented as 1K and 3K soft-copy images. Forty patients with and 40 patients without pneumothorax diagnosed on previous and subsequent digital storage phosphor radiography (SPR, gold standard) had follow-up chest radiographs with CsI/a-Si FDR. Four observers confirmed or excluded the diagnosis of pneumothorax according to a five-point scale first on the 1K soft-copy image and then with help of 3K zoom function (1K monitor). Receiver operating characteristic (ROC) analysis was performed for each modality (1K and 3K). The area under the curve (AUC) values for each observer were 0.7815, 0.7779, 0.7946 and 0.7066 with 1K-matrix soft copies and 0.8123, 0.7997, 0.8078 and 0.7522 with 3K zoom. Overall detection of pneumothorax was better with 3K zoom. Differences between the two display methods were not statistically significant in 3 of 4 observers (p-values between 0.13 and 0.44; observer 4: p=0.02). The detection of pneumothorax with 3K zoom is better than with 1K soft copy but not at a statistically significant level. Differences between both display methods may be subtle. Still, our results indicate that 3K zoom should be employed in clinical practice.

Keywords Radiography · Digital radiography · Technology-flat-panel detector radiography · Comparative studies pneumothorax

Introduction

Limited spatial resolution is one major disadvantage of digital radiography compared with screen-film radiography. Digital image postprocessing and unsharp mask filtering are technical features to compensate for this lack of spatial resolution. Even still, high-frequency structures, such as interstitial disease and pneumothorax, remain important challenges for newly developed digital imaging systems.

The cesium-iodide (CsI)- and amorphous-silicon (a-Si)-based flat-panel detector (FD) is a new-generation digital image acquisition system that provides high detective quantum efficiency (DQE) of about 70% [1], better modulation transfer function (MTF) than previous systems and a higher spatial resolution of 3.5 lp/mm [2]—DQE and MTF having been shown to be important physical measures of image quality [2, 3]. However, the diagnostic performance of an entire digital system is not only determined by the quality of the image acquisition but also by the medium of presentation. Diagnostic reading monitors are available with different matrix sizes of the digital screen ranging from 1,024×1,024 pixels (1K) to 2,048×2,048 (2K) and 4,096×4,096 pixels (4K). 4K-matrix monitors are very costly, and superiority over monitors with smaller matrix sizes is not proven [4]. The present discussion about the superiority of 2K monitors over 1K monitors in terms of diagnostic accuracy is still controversial, especially regarding the conspicuity of high-frequency pathologies such as interstitial disease and pneumothorax. Previously, phantom studies [4, 5] and comparison trials for the assessment of digital soft-copy versus digital hard-copy and conventional screen-film radiography, respectively, were reported [6–8]. Therefore, the present study compares the depiction of pneumothorax with the 3K acquisition matrix CsI/a-Si FDR when presented on 1K monitors with and without the 3K-matrix zoom function.

Subjects and methods

Patients

Forty consecutive patients from the clinical routine who presented pneumothorax on previous storage phosphor radiographs (SPR) were referred for FDR based on CsI and a-Si for follow-up chest X-rays in the posterior–anterior projection. All follow-up radiographs were performed within a maximum interval of 24 h. Etiology, localization and size of the pneumothorax and the presence of foreign bodies suggestive of pneumothorax, such as a central venous line, chest tube, port catheter system or pacemaker are listed in Table 1.

As a control group, 40 patients were chosen who were referred for thoracic CT for other purposes and in whom chest radiographs were clinically indicated. FDR of the chest was performed within a maximum interval of 72 h. Thoracic CT (performed at 140 kVp, 5-mm collimation,7.5-mm table feed, high-resolution kernel with 120-ml contrast medium, Ultravist, Schering, Berlin, Germany) confirmed the absence of pneumothorax or any other pathologic findings. The mean age of all 80 patients was 58 (range 31–78) years; gender ratio was 39 men to 41 women. Patient constitution was equivalent. No additional selection criteria were employed. Informed consent was obtained from all patients. The use of FDR technology for this purpose was approved by the local ethics committee review board.

Technical equipment

The large-area detector (43 cm×43 cm) of the dedicated chest X-ray system consisted of a photodiode matrix based on a-Si and a 500-µm scintillator layer of thallium-doped CsI. This system has been described previously [1, 2, 9]. Each pixel of the 3K matrix (3,000×3,000 pixels) has a size of 143 µm, resulting in a nominal spatial resolution of 3.5 line pairs per millimeter. The DQE is 70% at a dose equivalent of speed class 400, 90 kV and zero spatial resolution [1]. All CsI/a-Si FDRs of the chest were performed at a standard dose equivalent to speed S 400 (detector input dose 2.5 µGy) and 125 kVp (n=50) or with

Table 1 Characteristics of pneumothorax in 40 patients

Characteristics	Number/position	
Etiology of pneumothorax		
After puncture[a]	23	
Spontaneous	4	
Following CT biopsy	4	
Postoperative	9	
Localization of pneumothorax	Right	Left
	24	16
Size of pneumothorax[b]		
0 cm–1.5 cm	18	
>1.5 cm–3 cm	12	
>3 cm	10	
Presence of foreign bodies[c]	With pneumothorax	Without pneumothorax
Central venous line	6	9
Pacemaker	6	2
Port catheter system	5	8
Chest tube	6	8

CT computed tomography
[a]Puncture of subclavian vein for port catheter implantation, central venous line or pacemaker placement
[b]Distance between chest wall and visceral pleura on posterior–anterior view
[c]Foreign bodies indicative of potential pneumothorax

a low dose equivalent to speed class S 800 (detector input dose 1.25 μGy) and 117 kVp (n=30). SPRs were exposed at 117 kVp. Additional technical parameters of both the CsI/a-Si FDR and SPR (gold standard) are summarized in Table 2. All chest radiographs underwent post-processing with the same predefined parameter setting of spatial filtering and contrast optimization, which were optimized in a previous clinical setting. The raw data set of one CsI/a-Si FDR used a 14-bit digital contrast resolution (16,384 gray levels). After the transfer to the reading work station (MagicView 1000, Siemens, Erlangen, Germany), the resolution decreased 12 bits.

Data analysis

All 80 chest X-rays in the posterior–anterior projection were presented in random order on 1K-matrix, high-brightness reading workstations (MagicView 1000, 260 candela) under optimal conditions with minimized ambient light. Four board-certified radiologists blinded to the pathology and follow-up determined the presence or absence of pneumothorax according to a five-point ordinal confidence rating scale: 1=definitely absent, 2=probably absent, 3=undetermined, 4=probably present and 5=definitely present. The diagnosis was first set on the 1K-matrix full-size image and then with help of the zoom function on an image section with the original spatial resolution of the 3K-acquisition matrix. A 4-week interval was respected between the two reading sessions. The observers were encouraged to optimize the monitor presentation with the window function, and the reading time was not limited. All observers had long-term experience with chest imaging; two observers (R1 and R4) were particularly experienced in soft-copy reading of chest radiographs and FDR. Receiver operating characteristic (ROC) analysis was performed on these data using GraphROC software, Finland. All examinations included into this retrospective study were clinically indicated.

Results

The area under the curve (AUC) of ROC analysis for all observer performances, the standard deviation and the statistical comparison of all AUCs are listed in Table 3. Corresponding ROC graphs are presented in Fig. 1. According to the AUC, detection of pneumothorax for all raters was better with 3K-matrix soft-copy image than with the 1K image. In three of four observers, no statistically significant difference was found between 1K-matrix soft-copy reading and 3K-matrix soft-copy reading. In the fourth observer, detection of pneumothorax was significantly better with the 3K matrix (p=0.02) than with the 1K matrix (Table 3). An example of the depiction of pneumothorax with 1K-matrix and with 3K-matrix zoom function in the same patient is given in Fig. 2.

When limiting the analysis to the pneumothoraces with a distance of 3 cm or less between the pleural line and the thoracic wall, the results were similar, and the differences

Table 2 Technical data of large-area flat-panel detector (FD) based on amorphous silicon (a-Si) and thallium-doped cesium iodide (CsI) and storage phosphor plate radiography (FCR 9501, Fuji, Tokyo, Japan)

	Storage phosphor technology (FCR 9501, Fuji, Japan)	Amorphous silicon flat-panel detector technology (ThoraxFD, Siemens, Germany)
Detector input dose	3.7 μGy (S 400)	2.5 μGy (S 400) 1.25 μGy (S 800)
Exposure parameters	117 kVp	125 kVp (S 400) 117 kVp (S 800)
Automatic exposure control	Yes	Yes
Detector field size	35×43 cm (14×17”)	43×43 cm (17×17”)
Focus	0.6/1	0,6/1
Acquisition matrix	2K	3K
Pixel size	200 μm	143 μm
Spatial resolution	2.5 lp/mm	3.5 lp/mm
Antiscatter grid (ratio)	Movable (10/40)	Stationary (10/80)
Filtering	3.5 mm Al	2.9 mm Al, add. 0.1 mm Cu in S 800
Focus-detector distance	2.00 m	1.80 m

lp/mm line pairs per millimeter, *S400* speed class, *Cu* copper, *Al* aluminium

Table 3 Receiver operating characteristic (ROC) analysis of observer performance in the detection of pneumothorax using the 1K monitor with and without 3K-matrix zoom function for the four raters (R1–4): areas under the curve (AUC), standard deviation (SD) and statistical difference between AUCs (two-tailed paired Student's *t* test)

Observer	1K		3K		*P* value
	AUC	SD	AUC	SD	
R 1	0.7815	0.0367	0.8123	0.0320	0.1338
R 2	0.7779	0.0359	0.7997	0.0356	0.3232
R 3	0.7946	0.0346	0.8078	0.0323	0.4403
R 4	0.7066	0.0429	0.7522	0.0405	0.0264*
Pneumothoraces with a distance of 3 cm or less between the pleural line and the thoracic wall					
R 1	0.7842	0.042	0.7980	0.039	0.5196
R 2	0.7874	0.040	0.8155	0.038	0.1925
R 3	0.8162	0.036	0.8340	0.032	0.3194
R 4	0.6499	0.051	0.7075	0.049	0.0203*

*Statistically significant

remained not statistically significant in three of four observers (Table 3). Twenty-five false negative diagnoses were made by all four observers with the 1K-matrix presentation. In 21 of these cases, the pneumothorax had a size of less than 1.5 cm. In the remaining four patients, the pneumothorax measured between 2.1 cm and 2.3 cm. Twelve of these false negative diagnoses were corrected with the use of the 3K-matrix zoom function.

Discussion

The present study focused on observer performance in the detection of pneumothorax using 1K-matrix soft copies and 3K-matrix zoom function in digital FD chest radiographs. Although the overall performance was better for all observers with the 3K-matrix zoom function, no statistical differences were found in three of four observers between the diagnostic performance with 1K- and 3K-matrix presentation on the high-brightness monitors. These results are in contradiction with the findings of Otto et al., who analyzed high-frequency structures on a chest phantom with 1K- and 2K-monitor resolutions [5]. They concluded that 1K-monitor resolution is not sufficient for the diagnosis of pneumothorax.

There are several possible reasons for the discrepancy of the findings in these two studies. Firstly, the positive diagnosis of pneumothorax in the clinical routine is based on numerous direct and indirect signs that are independent of spatial resolution. A direct sign is identification of a fine linear opacity with a course parallel to the chest wall. Indirect signs of pneumothorax include asymmetry in the radiotransparency and increased translucency of a distinct lung area, the lack of pulmonary vascular structures beyond

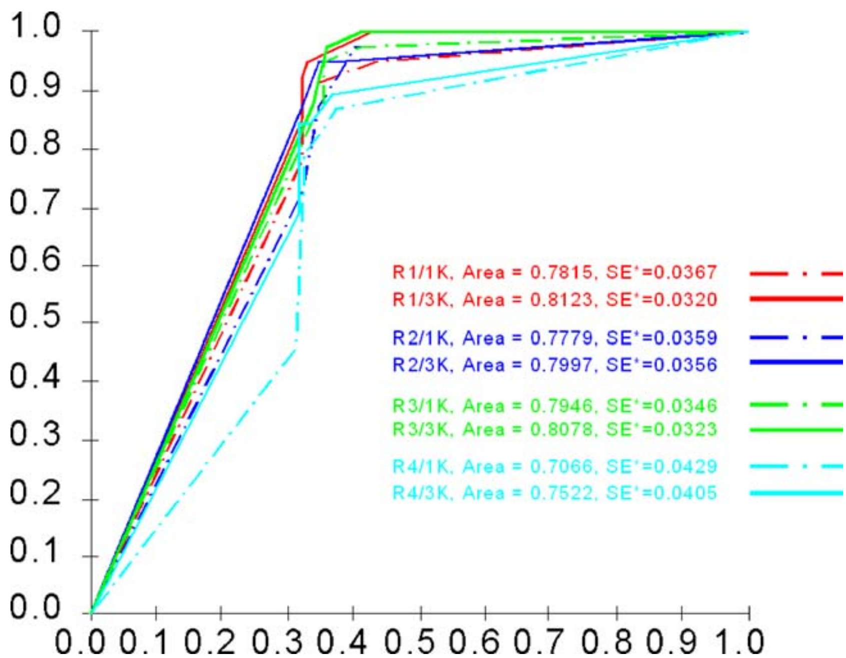

Fig. 1 Receiver operating characteristic (ROC) curves depicting observer performance in the detection of pneumothorax with 1K-matrix and 3K-matrix soft copies deriving from cesium iodide and amorphous silicon flat-panel detector radiography (CsI/a-Si FDR). *SE* standard deviation, *R* reader

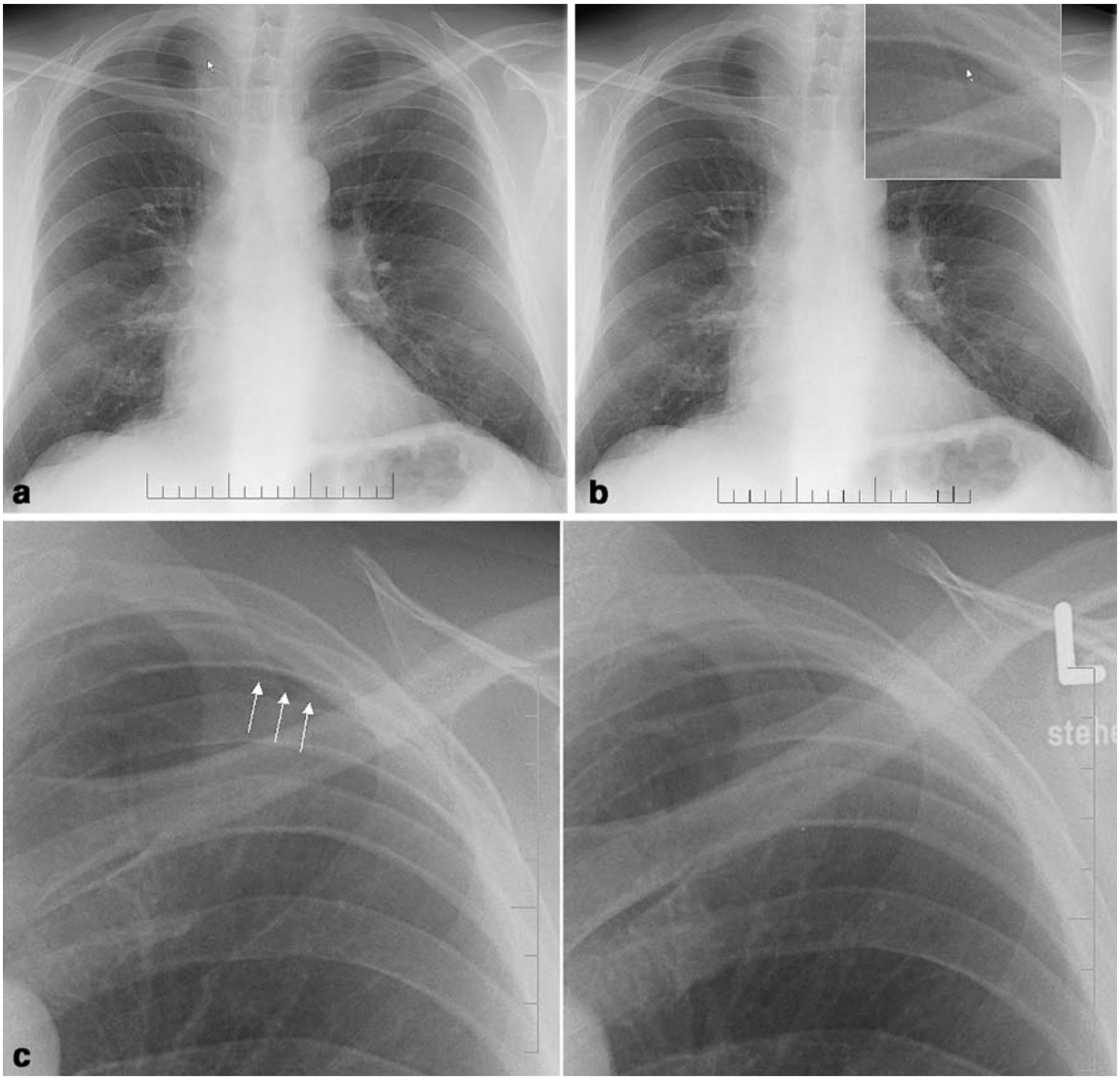

Fig. 2 A 62-year-old man with pneumothorax adjacent to the left lung apex. The very decent line of pleural margin can be hardly identified on the 1K-matrix soft-copy image (**a**) but is clearly depicted with the 3K-matrix zoom function focusing on the lung apex (**b**; *small white arrow*). Follow-up chest X-ray 1 week later shows complete remission of the pneumothorax (**c**). The 3K-matrix zoom focused on the apex of the left lung shows both radiographs in comparison with presence (*white arrows*) and absence of pneumothorax (**c**)

the pleural line even if it is not clearly identified and the presence of an air-fluid level in a seropneumothorax. These signs may additionally support the correct diagnosis of pneumothorax. Phantom studies [4, 5] only refer to the depiction of fine linear structures and therefore may not adequately reflect the clinical situation.

Secondly, the size of the pneumothorax may have a major impact on the detection of this pathology. Our analysis was not limited to subtle cases of pneumothorax, and instead comprised a wide range of sizes (maximum distance of pleural line to chest wall between 0.3 cm and 4.8 cm). Patients in our study were consecutively taken from the clinical routine, and we practiced no trial for discrete pathology in order to reflect the entire spectrum of presentation of pneumothorax in clinical routine. Large pneumothoraces with a gap of 3 cm and more between the pleural line and the thoracic wall were easily identified on 1K-matrix soft copies independent of the spatial resolution. Most of the false negative findings of pneumothoraces were found in the patient group with a pneumothorax at a pleuroparietal distance of less than 1.5 cm. Thus, one could speculate that the size of the pneumothorax may have impact on the detectability. Therefore, we limited the analysis to the subgroup of patients with a pneumothorax measuring 3 cm or less. Still, the statistical results did still not show significant difference between 1K-matrix and

3K-matrix reading. This corresponds to the statement of Fajardo et al. that pneumothorax size did not influence observer performance in their study [8]. In our study, the number of patients with subtle and small-size pneumothorax may be considered too small to prove statistically significant differences. This fact represents one major limit of this study and should encourage further studies on the depiction of small-sized pneumothorax with 1K and 3K matrices to challenge the limits of the either technical performance.

Thirdly, spatial resolution is a crucial factor influencing the visibility of fine linear structures and high-frequency lesions. While 1K-matrix resolution of soft-copy monitor reading is considered to be sufficient for the detection of low-frequency structures such as pulmonary nodules and mediastinal structures [4, 10], high-frequency pathologies, such as pneumothorax and interstitial disease, require a high spatial resolution and pixel size of 200 μm or less [6, 11]. Detection of pneumothorax is markedly inferior in soft-copy images derived from digital image-intensifier systems, providing only poor spatial resolution of 1.5 lp/mm (1K) [12]. In the detection of pneumothorax, various digital techniques have been the subject of performance studies: Kehler et al. did not find any differences between digital 1K hard-copy and 1K soft-copy images (1,024×1,024 pixels) in a phantom study using digital luminescence radiography [4]. Elam et al., on the other hand, conducted a clinical trial and found lower sensitivity with work-station readings (1,024×1,536 pixels) compared with screen-film and digital hard-copy readings [7].

Regarding a 2K-matrix resolution, observer performance in the detection of pneumothorax is reduced when reading digitized chest images on a monitor display rather than on digital hard-copy or screen-film radiographs [13–15]. According to Razavi et al., however, there are no significant differences in the detection of pneumothorax between 2K hard-copy and 2K soft-copy images of children's chest radiographs [16].

Although for three observers the differences between 1K- and 3K-matrix soft-copy readings were not statistically significant, there was a clear tendency to improvement of observer performance with use of 3K-matrix zoom function. This improvement is reflected in the markedly decreasing number of false negatives when using this visualization tool and thus referring to the full resolution. Bacher et al. could demonstrate a similar effect of magnification in the soft-copy reading of digital mammograms [17]. Magnification to full resolution significantly improved the image quality when using lower resolution devices. Three-megapixel monitors could then approach the quality of a 5-megapixel monitor in digital mammography when the magnification function was used [17]).

With the new FDR technology, several technical innovations have been developed to improve image quality [2]. The pixel size of 143 μm of the present CsI/a-Si FD results in a spatial resolution of 3.5 lp/mm of the acquisition image, which is superior to previous digital imaging systems [1]. On 1K-matrix monitors, the full-size image is presented with reduced spatial resolution that does not reflect the high spatial resolution of the acquisition system. With the use of the zoom function, a section of the image is enlarged and presented on the monitor with 3K spatial resolution of the acquisition matrix. Thus, to some extent, better performance with FDR and the 3K-matrix zoom function in the present setting might be attributed to higher spatial resolution. Furthermore, visualization of high-frequency structures is positively influenced by blowing up and focusing on a detail of the entire image. High DQE (DQE=70% at 90 kVp) and superior modulation transfer function (MTF) confirmed in technical and experimental studies [1, 3, 18], optimal contrast discrimination and spatial filtering and individual and optimized digital image postprocessing in FDR may additionally improve system performance independent of spatial resolution and thus compensate for the deficits of former digital radiography systems. One could hypothesize that these effects of optimized acquisition and postprocessing parameters in FDR technology may minimize the statistical differences between the two display modalities of the same image, making even the 1K image sufficient to detect pneumothorax.

Besides these technical parameters, the detection of pneumothorax in soft-copy reading is also dependent on other factors, such as the observer's experience with digital viewing systems, viewing time, ambient light, knowledge of the patient's history, presence of other pathologies on the radiograph, likelihood of presence of pneumothorax and psychological effects and working conditions. Major impact may be attributed to the observers' experience in chest radiography and the familiarity with soft-copy reading and operating postprocessing tools. Observer R4 in our study setting was most familiar with the flat-panel technology and the use of interactive visualization tools. Two of the remaining observers had longer experience with chest radiography so that the final statistical results of the study may also be influenced by the different levels of observer experience. The relevance of this potentially determining factor, however, is generally difficult to evaluate but may explain the differences, as in clinical routine.

Since viewing conditions tend to be ideal in the setting of a clinical study, it might be very difficult to demonstrate small statistical differences in the evaluation of pneumothorax. It may therefore be necessary to select particularly subtle abnormalities in order to detect significant differences between various imaging modalities using only a limited number of cases [6] or to increase the number of cases or observers.

In addition to the clinical performance of monitors, economic aspects need to be taken into account. Since there may be considerable differences in the costs of 3K and 1K monitors, the results of our study suggest that less expensive monitors with 1K spatial resolution may be sufficient in the diagnosis of pneumothorax if the 3K zoom function is available for a higher level of diagnostic accuracy.

Conclusions

Under study conditions limited to the detection of pneumothorax, the overall performance of all observers was better with the use of 3K-matrix resolution. In one out of four observers, detection of pneumothorax with 3K zoom was better at a statistically significant level. About half of all false negative diagnoses were converted into correct positive diagnosis with the use of the 3K-matrix zoom function. Although in the present study setting the differences between 1K and 3K soft-copy reading were not statistically significant, the use of the 3K-matrix acquisition size can be recommended outside the setting of a clinical study in order to achieve the highest diagnostic accuracy possible, especially with respect to other influencing factors under routine conditions.

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