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FULL PAPER

Dependency of image quality on acquisition protocol and image processing in chest tomosynthesis—a visual grading study based on clinical data

¹MASOUD JADIDI, MSc, ^{2,3}MAGNUS BÅTH, PhD and ^{4,5}SVEN NYRÉN, MD PhD

¹Departments of Clinical Science, Intervention and Technology, Karolinska Institutet, Stockholm, Sweden

²Department of Radiation Physics, Sahlgrenska Academy at University of Gothenburg, Gothenburg, Sweden

³Department of Medical Physics and Biomedical Engineering, Sahlgrenska University Hospital, Gothenburg, Sweden

⁴Molecular medicine and surgery, Karolinska institutet, Stockholm, Sweden

⁵Department of Thoracic radiology, Karolinska University Hospital, Stockholm, Sweden

Address correspondence to: Mr Masoud Jadidi

E-mail: masoud.jadidi@ki.se

Objective: To compare the quality of images obtained with two different protocols with different acquisition time and the influence from image post processing in a chest digital tomosynthesis (DTS) system.

Methods: 20 patients with suspected lung cancer were imaged with a chest X-ray equipment with tomosynthesis option. Two examination protocols with different acquisition times (6.3 and 12 s) were performed on each patient. Both protocols were presented with two different image post-processing (standard DTS processing and more advanced processing optimised for chest radiography). Thus, 4 series from each patient, altogether 80 series, were presented anonymously and in a random order. Five observers rated the quality of the reconstructed section images according to predefined quality criteria in three different classes. Visual grading characteristics (VGC) was used to analyse the data and the area under the VGC curve (AUC_{VGC}) was used as figure-of-merit. The 12 s protocol and the standard DTS processing were used as references in the analyses.

Results: The protocol with 6.3s acquisition time had a statistically significant advantage over the vendor-recommended protocol with 12s acquisition time for the classes of criteria, Demarcation ($AUC_{VGC} = 0.56$, $p = 0.009$) and Disturbance ($AUC_{VGC} = 0.58$, $p < 0.001$). A similar value

of AUC_{VGC} was found also for the class Structure (definition of bone structures in the spine) (0.56) but it could not be statistically separated from 0.5 ($p = 0.21$). For the image processing, the VGC analysis showed a small but statistically significant advantage for the standard DTS processing over the more advanced processing for the classes of criteria Demarcation ($AUC_{VGC} = 0.45$, $p = 0.017$) and Disturbance ($AUC_{VGC} = 0.43$, $p = 0.005$). A similar value of AUC_{VGC} was found also for the class Structure (0.46), but it could not be statistically separated from 0.5 ($p = 0.31$).

Conclusion: The study indicates that the protocol with 6.3 s acquisition time yields slightly better image quality than the vendor-recommended protocol with acquisition time 12 s for several anatomical structures. Furthermore, the standard gradation processing (the vendor-recommended post-processing for DTS), yields to some extent advantage over the gradation processing/multi-objective frequency processing/flexible noise control processing in terms of image quality for all classes of criteria.

Advances in knowledge: The study proves that the image quality may be strongly affected by the selection of DTS protocol and that the vendor-recommended protocol may not always be the optimal choice.

INTRODUCTION

Conventional chest radiography (CXR) is still the most common examination in order to establish a radiographic diagnosis of many pulmonary diseases. However, radiological examinations of the chest result in a large number of uncharacterized lung lesions that need follow up with CT, according to current recommendations.¹ For example, one study found that 9.4% of all chest CT resulted in a

recommendation for follow-up, adding to costs and strain on the healthcare system.² A technology with low radiation dose to the patient, short examination time, that is easy to use, is inexpensive and accessible—but still providing section images of the patient—is, therefore, of interest.

Digital tomosynthesis (DTS) has been proposed as a cost-effective method for follow up of accidental pulmonary

findings,³ although the performance of this technology compared to CT has to be further evaluated. With tomosynthesis technology, multiple separate exposures are made as the X-ray tube moves linearly in one direction during the exposure, resulting in an individual image for each exposure. The exposure dose of every single exposure is low and the individual exposures are recalculated into a three-dimensional volume and reconstructed into multiple coronal thin slices covering the entire volume.

The vendor recommended scanning time of chest DTS in the system used in this study is about 12 s. During the scan, the patient should stand still and hold the breath. As not all patients are able to hold their breath during this time period, the acquisition time and the resulting risk of breathing artefacts has been put forward as one of the main limitations of chest DTS in several reports.^{4–6} As a matter of fact, in a study comparing nodule detection between CXR and chest DTS, it was found that in patients with breathing artefacts the detectability of nodules was comparable between the two techniques.⁷ To put this into perspective, the sensitivity for nodules is commonly reported as being three times higher in chest DTS than in CXR for patients without breathing artefacts.^{8,9} Also, in a previous study, false-positive results in detection of diaphragmatic pleural plaques with DTS were seen in patients with breathing artefacts.⁴ Thus, it is of great interest to reduce the acquisition time in chest DTS, to reduce the risk of inducing breathing artefacts in the reconstructed images. Furthermore, a shorter acquisition time should also be beneficial for reducing other motion artefacts, resulting from, *e.g.* the difficulty in standing absolutely still during more than 10 s.

As motion artefacts degrade images in DTS, investigation of different acquisition times is an important part of the optimisation of image quality and this can determine the diagnostic yield in imaging.¹⁰ In a previous visual grading study based on an anthropomorphic chest phantom, a DTS protocol with acquisition time 6.3 s was found to yield images whose quality did not differ significantly for any class of image quality criteria from images obtained by using the protocol recommended by the vendor with acquisition time 12 s.¹¹ Possible advantages of the protocol with short acquisition time related to the reduced risk of breathing and other motion artefacts could for obvious reasons not affect the outcome of the phantom study. Thus, it is conceivable that this protocol actually could lead to increased image quality in the clinical situation.

The main purpose of the present study was to compare the quality of clinical chest DTS images obtained with two different protocols with acquisition time 6.3 and 12 s, available in the Fujifilm DTS system. An additional purpose was to compare two types of image processing—the vendor-recommended post-processing for DTS, including only gradation processing (GP), and additional post processing, including multiobjective frequency processing (MFP) and flexible noise control (FNC). This clinical trial included 20 patients with suspected lung cancer and a visual grading study was performed on 80 sets of images, according to predetermined quality criteria.

METHODS AND MATERIALS

Patient inclusion

Approval of this study has been obtained from the Regional Ethical Review Board in Stockholm, Sweden, and informed consent from all participants was obtained. From August 2014 to May 2015, 20 patients (12 males and 8 females with average age of 67 years (range 51–77 years), average weight of 84 kg (range 60–112 kg) and average length of 174 cm (range 160–191 cm) with suspected pulmonary malignancies, scheduled for PET-CT, were included in the study (Table 1). The patients had been referred to the Lung-Allergy Clinic, Karolinska University Hospital, for newly discovered lung lesions. For study purposes, two DTS examinations were additionally performed on each patient.

Imaging equipment

The chest tomosynthesis examinations were performed on an FDR AcSelerate (Fujifilm, Tokyo, Japan) chest X-ray equipment with DTS options. The system has a stationary Caesium Iodide flat panel detector ($43 \times 43 \text{ cm}^2$, resolution 2880×2880 pixels of $0.15 \times 0.15 \text{ mm}^2$). The projection images were transferred to the system's post processing unit, with software for DTS image reconstruction.

DTS protocols

Two DTS protocols [called tomosynthesis exposure ID (Identity) by the vendor] were included in the study. They differed in source-to-detector distance (SDD), X-ray tube swing angle, total exposure time and the number of exposures (Table 2). The tube voltage and filtration were kept constant but the tube current (mA) was altered for each protocol (Table 3) to achieve a constant effective dose of 0.4 mSv for both protocols¹² for a standard patient (170 cm/70 kg). Other settings, such as collimation of the X-ray tube, reconstruction condition and image post-processing parameters, were the same for both protocols. All additional image processing parameters besides the contrast and brightness were turned off as default for the original images. Under each tomosynthesis exposure ID, reconstruction conditions can be set in the application of tomosynthesis viewer. The reconstruction conditions consist of centre (slice height), slice range and pitch (spacing of the slices). Those conditions are initialized as default in the systems' service utility by the vendor. However, the end user is able to change the settings afterwards if it is needed. (Table 2). Height of the centre slice is the distance between middle of the object and the surface of the patient positioner for an exposure in the supine or upright position. Slice range is the total thickness of the reconstructed object and the pitch presents the distance between two slices. Two different reconstruction algorithms are available in this system, shift-and-add (SAA) and filtered back projection (FBP), which is recommended by the vendor.

By shift-and-add reconstruction technique, the objects in a given plane are brought into focus, while structures in other planes are blurred. However, the deblurring algorithm, filtered back projection, has been used by many vendors in order to reduce the blurred out-of-plane anatomy.¹³

Table 1. Clinical statue of the study populations

Patient	Age	Sex	Smoker/ Non-smoker	Time since cessation (y)	Comorbidity	Current symptoms	Final diagnosis
1	65	M	Former	17	None	Fever, cough, weight loss	Low differentiated NSCLC
2	78	M	Former	15	Diabetes, cardiac infarct, parotid cancer	Cough	NSCLC, probably adenocarcinoma
3	71	M	Smoker	n/a	Prostate cancer, diabetes, hypertension, gout	Accidental finding (clinical trial)	Adenocarcinoma
4	68	F	Former	30	Hypertension	Cough	Adenocarcinoma
5	64	M	Former	10	Hypertension	Accidental (check-up)	Benign
6	75	M	Former	10	Hypertension	Cough, malaise	Adenocarcinoma
7	61	M	Former	19	None	Haemoptysis, cough	Squamous cell carcinoma
8	57	M	Never-smoker	n/a	None	None	Benign
9	57	F	Smoker	n/a	Hyperthyroidism, hyperlipidemia	Cough	Adenocarcinoma
10	74	M	Smoker	n/a	COPD, hepatocellular cancer	None	Benign
11	67	F	Smoker	n/a	Suspected COPD, hypertension, atrial fibrillation, heart failure	Back pain	Small cell lung cancer
12	70	F	Former	34	Hypertension, bladder cancer	None	Benign
13	71	M	Former	20	Hypertension, diabetes, obesity, GIST tumour of the stomach		Benign
14	72	F	Smoker	n/a	Diabetes type 2, hypertension	Hoarse, swallowing difficulties	Benign
15	57	M	Former	17	Diabetes type 1		Adenocarcinoma
16	55	M	Never-smoker	n/a	Hypertension	Some cough	Adenocarcinoma
17	75	F	Former	39	Pulmonary embolism	None	Adenocarcinoma
18	75	M	Former	10	Vascular intervention of the legs	None	Adenocarcinoma
19	51	M	Smoker	n/a	None	Haemoptysis, cough	Benign
20	70	F	Smoker	n/a	None	Repeated infections	Squamous cell carcinoma

COPD, chronic obstructive pulmonary disease; NSCLC, non-small cell lung cancer; GIST, gastrointestinal stromal tumour.

Imaging procedures

For each patient, two acquisitions in the posteroanterior (PA) direction in upright position were performed (Figure 1) in a random order, and then reconstructed into coronal section image series. The patient was instructed to hold his/her breath

during the two acquisitions. During exposure, the detector unit (chest unit) was fixed but the X-ray tube moved linearly in the α -direction (down to up). To prevent motion artefacts caused by vibration movements of the X-ray tube and to increase the reconstruction accuracy, two markers were placed on the detector on

Table 2. Exposure data for the two chest DTS protocols assessed in the study

Exposure conditions for Tomosynthesis				Reconstruction conditions					
DTS exposure ID	SDD (cm)	Tube swing angle (°)	Total exposure time (s)	Reconstruction algorithm 0:SAA 1:FBP	No. of exposures	Centre height (mm)	Range (mm)	Pitch (mm)	No. of slices
65	130	20	6.3	1	32	150	260	5	53
76	180	27	12.0	1	60	150	260	5	53

DTS, digital tomosynthesis; FBP, filtered back projection; SDD, source-to-detector distance.

Table 3. X-ray conditions for the two DTS protocols assessed in the study

DTS exposure ID	Kv	Per projection [mAs]	Q per projection [mA]	Projection time [ms]	Calculated total mAs
65	120	0.8	100	8	25.6
76	120	0.8	104	8	49.9

All tomosynthesis projection images were acquired with a filtration of 3.0 mm Al and + 0.2 mm Cu and two different grids, with aluminium interspace, were used; a grid with ratio 10/1 with a focusing distance of 130–140 cm for the protocol with SDD 130 cm and a grid with ratio 12/1 with a focusing distance of 180 cm for the protocol with SDD 180 cm. Large focal spot size were used for both protocols.

both sides of the patient. According to the radiographer who performed all examinations, none of the patients had difficulties with holding the breath during acquisitions. The reason was that the radiographer needed approximately 4 min in order to exchange the grids (one for SDD 130 cm and, another one for SDD 180 cm) between the two acquisitions. During that time, the patient had time to recover his/her breath.

Image processing

In order to find out the impact of the post-processing parameters on the image quality in both protocols, each tomosynthesis series was processed with two different post-processing: the post-processing recommended by the vendor for chest DTS and the post-processing used clinically at the hospital for PA CXR. The recommended post-processing for chest DTS consisted of the GP, which covers the digital input data with only appropriate

density and contrast. The post-processing for PA CXR used additional parameters beyond GP such as MFP and FNC (Table 4).

MFP selectively applied varying degrees of edge enhancement processing to each individual structure depending on size. MFP also improves greyscale shadows that equalize the densities and contrast of the final image. The MFP has two functions, frequency enhancement for enhancing shadows and dynamic range control (DRC) process.^{14,15} Dynamic range control process is performed to depict the poorly visible part of the image, *e.g.* mediastinum, without changing the density or contrast of the most important region of interest.^{16,17} FNC selectively suppresses noise components to improve the granularity, particularly in medium- to low dose area, while maintaining the contrast.¹⁵

Image evaluation

In total, there were four DTS series for each patient (protocols with 6.3 and 12.0 s acquisition time; each acquisition processed with two different types of post-processing) (Figure 2), resulting in a total of 80 chest DTS series for the 20 patients. The quality of the reconstructed DTS series was evaluated in a visual grading study, conducted using the software ViewDEX.^{18–20} ViewDEX is a freeware image viewer for conducting different types of observer performance experiments in an efficient way, developed at Sahlgrenska University Hospital, Gothenburg, Sweden. In ViewDEX, the image series are displayed in a unique random order for each observer along with a set of criteria and the responses of the observer (given rating for each criterion) are registered and stored in a log file for analysis. In visual grading, the observer determines a subjective evaluation by using a rating scale that can be either absolute or relative. In absolute visual grading the images (or image series) are evaluated one at a time on an absolute scale whereas in relative visual grading the images are compared side by side, using a relative scale and one or more images for comparison. In the present study, absolute visual grading was used.

The interface (Figure 3) and type of the questions were designed for this study. Before the observers started the evaluation of the images, they were instructed to go through a training set, containing test cases. The criteria (Table 5) developed for the study, were based on the European guidelines on quality criteria for diagnostic radiographic images^{21,22} and the quality criteria proposed in previous studies.^{11,23} The criteria focused on image quality in pre-determined anatomical regions, similar to our previous publication.¹¹ Image quality was assessed in five defined anatomical regions. In four regions, (1) basal–dorsal, (2)

Figure 1. A chest tomosynthesis examination is performed with the patient standing in the PA. Information was derived from Fujifilm, Tokyo, Japan. PA, posteroanterior.

Table 4. Description of image processing¹⁴

IPP	GP				MFP						FNC			
	GA	GT	GC	GS	MRB	MRT	MRE	MDB	MDT	MDE	FFC	FNB	FNT	FNE
Series 1	1.0	e	1.6	0.0	–	–	–	–	–	–	–	–	–	–
Series 2	0.9	e	1.6	–0.10	C	R	0.6	A	C	0.6	A	E	B	0.4

FFC, filter control of FNC, to determine to what extent FNC is to be applied depending on the X-ray radiation dose; FNB, balance type of FNC, to determine to what extent FNC is to be applied in relation to frequency components; FNC, flexible noise control; FNT, the type of FNC, to determine to what extent FNC is to be applied to image density. FNE, the enhancement of FNC, to determine to what extent FNC is to be applied; GA, (gradation amount): adjustment of the contrast. As the numeric value increases, the contrast becomes enhanced; GT, (gradation type): A non-linear gradation curve, e.g. "e" curve represents for chest menu; GC, (gradation centre): centre for a density when GA value is changed. GP, gradation processing; GS, (gradation shift): adjustment of the density, at the numeric value increases, the density becomes enhanced; MRB, (multifrequency balance), a factor that determines frequency band when applying image enhancement; MDB, multiDRC balance type, a factor that determines the dynamic range (DR) compression processing; IPP, image processing parameters; MDT, multi-DRC enhancing type, a factor that determines density area of DR compression processing; MDE, degree of multiDRC enhancement; MFP, multiobjective frequency processing; MRT, multi-frequency enhancing type, a non-linear curve which changes the degree of enhancement according to the image density; MRE, The factor of adjustment of multifrequency enhancement.

basal–ventral (3) peripheral vessels– lateral part of the right lung and (4) retrocardiac (behind the heart), vessels were assessed. Demarcation of small vessels (1–3 mm) and the disturbance from structures in front or behind were rated in these locations. In the fifth region, the spine, demarcation of finer structures was rated.

Figure 2. The DTS series with 12 and 6.3 s acquisition times, were first reconstructed according to the recommendation by the vendor (standard processing) and transferred to the PACS. Then the same reconstructed DTS images were reprocessed with the same image processing parameters as the current conventional chest images and transferred to PACS. DTS, digital tomosynthesis; PACS, picture archiving and communication system.

Four senior consultant radiologists, each with more than 20 years of experience, and one senior pulmonary physician participated as observers in the study. The study was conducted on a MacBook Pro, 15" Retina display with a 2880 x 1800 resolution. 15" Retina models feature two graphics cards and each is powerful enough to utilize the high-resolution display. All observers evaluated the images on the same display, using ViewDEX DICOM reader software. For each series, the observers rated the image quality related to each criterion on a 5-step ordinal scale: (1) very bad, (2) bad, (3) fair, (4) good, and (5) very good. The images were identified only by a code unrelated to the type of protocol and post processing.

VGC and statistical analysis

To analyse the data, visual grading characteristics (VGC) analysis was used.^{24,25} VGC analysis is a non-parametric, rank-invariant statistical method developed for analysis of visual grading data. In VGC analysis, the ratings for two protocols (a reference protocol and the test protocol) are compared by creating a VGC curve, similar to how the ratings for normal and abnormal cases in receiver operating characteristics (ROC) analysis are used to create a receiver operating characteristics curve. A VGC curve is constructed for each criterion (or class of criteria) and reflects

Figure 3. The interface of ViewDEX 2.0 adapted to VGC study in chest tomosynthesis. VGC, visual grading characteristics.

Table 5. The criteria developed for the present study to rate the image quality of the reconstructed digital tomosynthesis (DTS) slices

Criteria	Structure
Demarcation	Basal dorsal, vessel demarcation (small vessels)
	Basal ventral, vessel demarcation (small vessels)
	Peripheral vessels, (upper, lateral right), vessel demarcation (small vessels)
	Retro cardiac, vessel demarcation, vessel demarcation (small vessels)
Disturbance	Basal dorsal, disturbance of vessels in front/behind
	Peripheral vessels (upper, lateral right), disturbance of vessels in front/behind
	Retro cardiac, disturbance of vessels in front/behind
	Basal ventral, disturbance of vessels in front/behind
Structure	Definition of bone structures in the spine

how the proportion of images that are judged as being of higher quality than a certain threshold for the test protocol (on the y-axis) varies with this proportion for the reference protocol (on the x-axis), when the threshold is altered. The VGC curve, thus, ranges from 0.0 to 1.0. The deviation from the diagonal is a measure of how much the two protocols differ in image quality. Normally, the area under the VGC curve (AUC_{VGC}) is used as a scalar measure of this difference.^{26,27} An AUC_{VGC} of 0.5 for a given criterion reflects similar image quality for that criterion for the two protocols. An $AUC_{VGC} > 0.5$ indicates higher image quality, and an $AUC_{VGC} < 0.5$ indicates lower image quality, for the test protocol than for the reference protocol.^{24,25}

Two VGC analyses were performed. In the first analysis, the two acquisition protocols (ID 65 and ID 76) were compared, using acquisition protocol ID 76 as the reference protocol and ID 65 as the test protocol. In the second analysis, the two post-processing types (GP only and GP/MFP/FNC) were compared, using standard processing (GP) as the reference protocol and GP/MFP/FNC processing as the test protocol. In both analyses, all observer data were included, meaning that data from both processing types were used when analysing the difference due to acquisition protocol and vice versa. Before the statistical analysis, the observers' ratings for the different criteria were grouped to create three classes of criteria: demarcation (four criteria), disturbance (four criteria), and structure (one criterion) (Table 5).

The VGC analysis was performed for each class of criteria using the software VGC Analyzer.^{28,29} This software determines the AUC_{VGC} averaged across observers, and a bootstrapping (resampling) technique is applied to determine the asymmetric 95% confidence interval of the AUC_{VGC} . An example of an obtained VGC curve is given in Figure 4. The p-value for the null hypothesis ($AUC_{VGC} = 0.5$) is determined using a resampling and permutation technique. In the present study, the statistical analysis of the AUC_{VGC} was based on the binormal VGC curve, and a random-reader analysis was used for the results to be generalizable to the

Figure 4. An example of a VGC curve, reflecting how the proportion of images that are judged as being of higher quality than a certain threshold for protocol identity ID 65 (with acquisition times 6.3 s) varies with this proportion for protocol ID 76 (with acquisition times 12 s), when the threshold is altered, for the disturbance class of criteria.VGC, visual grading characteristics.

population of observers. Since the same patients were included in all comparisons, a paired-data analysis was used. A p-value < 0.05 was considered statistically significant.

RESULTS

The VGC analysis showed a small but statistically significant advantage for the protocol ID 65 with 6.3 s acquisition time over the vendor-recommended protocol ID 76 with 12 s acquisition time (used as reference in the analysis) for the classes of criteria demarcation ($AUC_{VGC} = 0.56$, $p = 0.009$) and disturbance ($AUC_{VGC} = 0.58$, $p < 0.001$). A similar value of AUC_{VGC} was found also for the class definition of bone structures in the spine (0.56), but this value could not be statistically separated from 0.5 ($p = 0.21$).

Regarding the type of processing, the VGC analysis showed a small but statistically significant advantage for the standard GP processing (used as reference in the analysis) over the GP/MFP/FNC processing for the classes of criteria demarcation ($AUC_{VGC} = 0.45$, $p = 0.017$) and disturbance ($AUC_{VGC} = 0.43$, $p = 0.005$). A similar value of AUC_{VGC} was found also for the class structure (0.46), but this value could not be statistically separated from 0.5 ($p = 0.31$).

DISCUSSION

This present study was designed with the main aim to investigate the difference in image quality between two different protocols with acquisition time 6.3 and 12 s available in the Fujifilm DTS system. An additional aim was to compare two types of

Table 6. The three classes of criteria

Classes of criteria	No of series	No of observers	No of criteria	Number of ratings
Demarcation	20	5	4	400
Disturbance	20	5	4	400
Structure	20	5	1	100

Demarcation consisted of the four assessments of vessel borders for each protocol. Disturbance consisted of the four assessments of disturbance from surrounding vessels. Structure was composed of the ratings for the two mediastinal structures.

image processing, standard post-processing intended for DTS and more advanced post-processing optimized for CXR. It was found that the tested protocol (ID 65) gave a small image quality advantage, for both the demarcation and disturbance classes of criteria, compared to the vendor-recommended protocol (ID 76) and with the clinically important advantage of a shorter acquisition time (6.3 vs 12 s). For the remaining criterion (definition of bone structures in the spine), no significant difference between the two protocols was obtained, possibly due to the study being underpowered for this criterion (see the smaller number of data points in Table 6). It could also be that the reproduction of high-contrast in-plane structures is more dependent on the in-plane resolution, which is less affected by the acquisition protocol than is the depth resolution. Regarding post-processing, a small image quality advantage was obtained with the standard DTS processing for the demarcation and disturbance classes of criteria, whereas no statistically significant difference was obtained for the bone structure criterion.

In order to reach the optimal image quality for obtaining the diagnostic of the images, it is essential to eliminate two kind of artefacts which can appear during acquisition. One is the patient motion artefact due to organ movement, patient tremors and heartbeat and the other one is the respiratory motion artefact.^{6,7} There are two main image quality advantages of a shorter acquisition time. The first one is reduction of the blur in the images due to patient motion,³⁰ especially elderly patient. For those patients, a short acquisition time (6.3 s) is essential without compromising the image quality.¹¹ The second advantage is a reduction of the risk of presence of the respiratory motion artefact. According to the radiographer, all patients in this study could hold their breath without any difficulty during the question time 6.3 and 12 s. However, previous studies have reported motion artefacts as one of the main reason for reduced visibility in DTS.^{31,32}

In addition to the difference in acquisition time, there are two other acquisition parameters affecting the image quality that differ between the protocols. These are the projection image density (the number of projections divided by the sweep angle) and the tube swing (or sweep angle). When the projection image density is too low, ripple will appear by the imperfect blurring of high-contrast structures outside the reconstructed plane.¹⁰ Given that protocol ID 65 has a lower projection density (1.6 compared with 2.2 for protocol ID 76), it is conceivable that this would lead to increased risk of ripple artefacts. However,

one of the observers (with more than 20 years' experience in Thoracic radiology) reviewed all images in order to evaluate the ripple artefact for both protocols without finding any significant ripple artefacts in any of the images. The second important parameter, the tube swing, will directly impact the depth resolution. A previous study has reported that by increasing the sweep angle the depth resolution will be improved, which results in a more accurate diagnosis of fine anatomy.¹⁰ In the present study, it was anticipated that the improved depth resolution for protocol ID 76 would affect the result for the disturbance class of criteria (disturbance of vessels in front/behind). However, no such effect could be seen, possibly due to the results being more affected by other parameters. For example, a reduced depth resolution (corresponding to a larger slice thickness) leads to lower image noise, which may lead to an increased signal-to-noise ratio for certain image details. It could also be that the difference in tube angle (20° vs 27°) was too small for the resulting difference in depth resolution to affect the results significantly.

Chest CT is still the golden standard for diagnosis of chest disease, *e.g.* detection of nodules and pulmonary metastases in patients with thoracic malignancy. However, CT in relation to DTS is more expensive and delivers a significantly higher radiation dose, which has a substantial impact on the effective dose to the patient population. Furthermore, DTS could be more available and easier to schedule compared to CT. In case of doubtful or cancer suspected findings on CXR, a low-dose CT can be performed. This, however, requires a rescheduling of the patient. An alternative would be to directly perform a DTS, with a short acquisition time without the patient leaving the CXR lab. Thus, DTS could be implemented as part of the routine diagnostic in the daily workflow and reduce both the cost and the need of CT for, *e.g.* suspect pulmonary lesion.^{33–35} Even if the ability of CT to detect new lesions is very good, various studies have shown that nodule size measurement on chest tomosynthesis and CT images are comparable, when the nodules are visible on chest tomosynthesis images.^{8,36,37} This means that in the case of follow-up CT, tomosynthesis might be sufficient to detect growth of known lesions.

The vendor recommends only GP-parameters, so as far as we are aware, this is the first time that those two post-processing parameters group (GP and MFP/FNC) have been compared for chest DTS images. In this study, FNC processing was performed at the certain level of suppression in all density area of the anatomical region. However, the effect of FNC processing was poor in high density of anatomical region. The MFP processing was used to enhance the image sharpness, in addition to optimize and improve a density area of a partly darkened or brightened image without changing the level of density. Hence, normally, when FNC is being applied, the degree of frequency enhancement is to be increased by either changing the MRT curve or increase the degree of enhancement by increasing MRE. Therefore, further study, which takes variable parameters of image density (FNC) in relation to frequency enhancement into account (MFP), is needed to be undertaken.

This study has several limitations. First, although the disturbance class of criteria indirectly took the depth resolution into account, there was no quality criterion that was aiming at directly assessing the depth resolution. A second limitation of this study is that there are no established quality criteria for chest tomosynthesis. For this study, the criteria instead had to be developed based on the European guidelines for diagnostic radiographic images²¹ and chest CT²² and additionally based on a previous study.¹¹ A third limitation is that the chest DTS images were evaluated on a laptop, Mac Book Pro, 15" and not on the hospital's picture archiving and communication system workstation used for routine clinical radiology. The reason for this was that two of the observers worked at different hospitals with different geographic location. Therefore, the DTS images were transferred to an external laptop to enable all observers to perform the study on the same system. However, the image quality of the monitor was deemed satisfactory by an experienced thoracic radiologist prior to the study. The fourth limitation is the relatively small number of patients. The reason was the logistical challenge of referring patients from the Lung-Allergy Clinic, Karolinska University Hospital Solna, to the Radiology department for tomosynthesis examination. However, all included patients underwent both

examination protocols, which increased the power of the study. The final limitation of the present study is that it is based on a selection of only two acquisition protocols—the vendor-recommended settings and those suggested by a previous phantom-based study.¹¹ Although this met the requirements of the study, clinical follow-up studies are necessary before it can be stated that any of those two protocols is the optimal one.

In conclusion, the chest protocol with 6.3 s acquisition time was found to yield image quality for different anatomical structure slightly better compared to the vendor recommended protocol with acquisition time 12 s. Furthermore, the standard GP processing (the vendor-recommended post-processing for DTS), yields to some extent advantage over the GP/MFP/FNC processing in terms of image quality for all classes of criteria.

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