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Effects of electrocardiogram gating on CT pulmonary angiography image quality

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Abstract

Introduction: Pulmonary embolism (PE) is the third most common cause of death from cardiovascular disease. Computed-tomographic pulmonary angiography (CTPA) is an accurate and safe test for diagnosing PE. The aim of this retrospective analysis was to evaluate the effects on image quality (IQ) of electrocardiogram (ECG) gating during CTPA.
Methods: Fifty consecutive patients presenting for CTPA were included in the study. A single acquisition was performed, resulting in two reconstructions: one at 75% of the R–R interval and the other without ECG influence. IQ evaluation was undertaken by two radiologists, focusing on respiratory and cardiac motion, image noise, low-contrast resolution, vessel and lung clarity, contrast media opacification and artefacts. Various regions of the lungs and vasculature were evaluated, and IQ scores were statistically compared.
Results: For the ECG-tagged reconstructions, IQ was noted to be better overall with regard to vessel clarity ($P < 0.05$) and cardiac motion ($P < 0.05$), while lung clarity was better only in the left lower zone ($P < 0.05$). IQ was better with regard to image noise ($P < 0.05$) and low-contrast resolution ($P < 0.05$) in the non-ECG-tagged reconstructions. No statistical IQ difference between the two types of reconstruction was noted with regard to respiratory motion, contrast media opacification or presence of artefacts.
Conclusion: The two types of reconstruction provide complementary information for evaluating CTPA results.

Key words: cardiopulmonary anatomy; computed tomography; ECG gating; pulmonary embolism; vascular.

Introduction

Pulmonary embolism (PE) is the third most common cause of death from cardiovascular disease after myocardial infarction and stroke.[1] In the United States it has an incidence of 69 per 100 000 patients, with 175 000 new cases occurring every year[2] and a mortality rate as high as 30–60%.[1,3,4] In the recent past, ventilation–perfusion lung scans, performed in nuclear medicine departments, were the most common investigative tool for suspected pulmonary embolism; however, 60–70% of these scans are deemed non-diagnostic.[2,5] Computed-tomographic pulmonary angiography (CTPA) is the imaging modality of choice when investigating for the presence of PE. This is largely due to multidetector CT (MDCT) scanning technology, which enables routine use of thin-slice data with improved low-contrast resolution, improved spatial resolution, and shorter scan times due to better temporal resolution as well as to its use of tools for optimising the timing of the contrast bolus. Today CTPA is regarded as an accurate and safe test for diagnosing PE, as it has improved visualisation of segmental and subsegmental pulmonary arteries[6] such that over 90% of subsegmental pulmonary arteries can now be visualised.[7] CTPA has a sensitivity of 62–78% and a specificity of 86–95%, according to a large multicentre research study.[8] Among clinical centres the protocol for acquiring a CTPA study varies significantly[9]; however, it would be advantageous to find a more stable and uniform protocol for the implementation of CTPA studies to increase the sensitivity and specificity of CTPA examinations.

Pulmonary arterial structures are influenced by cardiac motion, which can induce artefacts such as blurring of vessel edges, dark shading in the otherwise bright column

of contrast within vessels and double-line artefacts along the long axis of a vessel.[10] Electrocardiogram (ECG) gating was initially developed for imaging of the coronary arteries to reduce artefacts produced by the moving heart.[11] Electrocardiogram gating during CTPA has not been widely adopted in scanners with limited *z*-axis detector coverage due to the resultant longer scan times and greater radiation exposure.[12] The latest CT scanners, with faster rotation times, additional detector rows and more powerful X-ray tubes that allow fast volume coverage, enable better ECG-gated CT scanning of the entire chest within a single breath-hold.[13] Applying ECG gating during CTPA examinations can reduce cardiac motion and aortic pulsation artefact and may improve pulmonary vessel clarity, particularly in regions adjacent to the heart borders and around the lung hila, thus potentially leading to better accuracy in diagnosis of pulmonary embolism and better overall image quality (IQ).

The aim of this prospective study was to evaluate motion reduction and IQ changes with ECG gating during CTPA.

Methods

Patients

Fifty-two consecutive patients of all ages and both sexes who presented to the emergency department of a tertiary referral centre for suspected PE were referred for CTPA between March and September 2011 and included in this study. Two patients who were uncooperative in that they were confused and unable to breath-hold were excluded, leaving 50 data sets available for analysis. The study was approved by the institutional ethics committee.

Heart rate

All examinations were acquired without modification of heart rate. No beta-blocking agents were administered for the purposes of this study; however, no investigation into patients' medication was undertaken to ascertain use of beta blockers prior to CTPA examination. The heart rate of each patient during CT scanning was recorded.

CT scanning

The CTPA examinations were undertaken using a 128-slice MDCT scanner (Ingenuity, Philips Healthcare, Cleveland, OH, USA). Each examination was acquired using the same protocol. Retrospective ECG-gated helical CTPA was undertaken in the craniocaudal direction, covering the lung fields from apices to bases. The scanning parameters were as follows: detector collimation of 64×0.625 mm, 400 ms per gantry rotation, pitch of 0.299 and tube voltage of 100 kVp. Each study utilised an automated dose suggestion, which varied with patient size. Tube current was modulated in order to reduce radiation dose.[14] In addition, ECG-correlated tube current modulation and multisector reconstruction were utilised for the varying heart rates,[15] with the dose peak centred at 75% of the R–R interval (to obtain a still phase in end diastole) and lower doses for the remainder of the cardiac cycle. No ECG padding (phase tolerance) was applied to the protocol. Each patient was irradiated only once. This scanning protocol had default parameters that matched the radiation dose delivered during an ungated CTPA examination. The use of ECG gating did not increase the radiation dose.

Intravenous contrast media injection protocol

One hundred millilitres of intravenous contrast media (iohexol 350 mg I/mL; Omnipaque 350 (GE Healthcare, Milwaukee, WI, USA)) was injected at a rate of 4 mL/sec through a 20-gauge intravenous cannula in the antecubital fossa. Each examination was triggered using a bolus-tracking technique whereby the scan began automatically when the region of interest placed in the pulmonary trunk had reached a radiodensity of 130 Hounsfield units.

CT image reconstruction

Reconstruction with retrospective ECG gating produces images that are centred at a selected percentage of the R–R time interval of the ECG trace.[16] All percentages of the R–R time interval from any ECG cycle during the acquisition may be reconstructed. Although each patient underwent only one CT acquisition, two fine-slice data sets were reconstructed from the available raw data. The fine-slice data sets were reconstructed with 0.9-mm axial slices overlapped every 0.45 mm on a B (soft) filter with the same level of iterative reconstruction (iDose4, Philips Healthcare). The difference between the two data sets was that one was reconstructed with ECG tagging centred at 75% of the R–R interval (referred to as 'tagged' data), whereas the other was reconstructed from the raw data without any consideration of the ECG trace information influencing the reconstruction (referred to as 'untagged' data).

Traditional helical raw data acquisition utilises spatial interpolation, and an image is produced from at least 180 degrees of data. Reconstruction to an ECG trace still requires 180 degrees of raw data; however, the 180 degrees can be made up of data from multiple sectors comprising different portions of the arc that sum to 180 degrees or more. For example, four sectors could comprise 45 degrees each to sum to 180 degrees.[17] Each of these sectors can be taken from different cardiac cycles, although they must be taken at the same phase point (75%). This means that the resultant image has improved temporal resolution, as it is made up of sectors, which inherently have shorter time periods, contained within the data.[18] Untagged data differ because the ECG trace that

Table 1. Image quality ranking system

Indicator	1	2	3	4	5
Clarity of vessels	Not assessable	Poor	Fair	Good	Excellent
Clarity of lungs	Not assessable	Poor	Fair	Good	Excellent
Respiratory motion	Excessive	Significant	Moderate	Minimal	None
Cardiac motion	Excessive	Significant	Moderate	Minimal	None
Presence of other artefacts	Severe	Mild	Moderate	Minimal	None
Low-contrast resolution	None	Poor	Fair	Good	Excellent
Contrast media opacification	None	Poor	Fair	Good	Excellent
Image noise	Excessive	Significant	Moderate	Minimal	None

defines phase points within the data is ignored. These data are reconstructed like a regular CT scan, using 180 degrees or more of spiral interpolated data. The data for where the dose is increased at the 75% phase point and the data for where the dose is dropped away from the 75% phase point are merged into one for reconstruction. Thus, temporal resolution is not optimised in the reconstructed images. These data closely simulate a routine CTPA helical acquisition without ECG gating.

Assessment of CT images

Both tagged and untagged data sets for every patient were deidentified and randomised. Two independent thoracic radiologists, each with greater than 15 years' CT experience, who were blinded to the image type (ECG-tagged or untagged) evaluated each data set for IQ with the use of a thin client workstation (Intellispace Portal, Philips Healthcare). A five-point ranking system was used to assess IQ with reference to the assessor's appraisal of cardiac and respiratory motion, image noise across structures, low-contrast resolution, clarity of vessels and lungs, contrast media density and the presence of other artefacts. Each indicator of IQ mentioned was analysed in each of the following anatomical regions: right and left upper zones, right and left middle zones, right and left lower zones, right and left main pulmonary arteries. A sliding scale of 1–5 was utilised for the IQ assessment, with a definition of each ranking as given in Table 1. All of the IQ scores for all data sets reviewed by both radiologists were collated and compared.

Statistical analysis

Data were analysed using SAS software version 9.2 (SAS Institute, Cary, NC, USA). The difference between tagged and untagged IQ scores for various CT IQ indicators were estimated using repeated-measures analysis of variance, with results reported as parameter estimates and standard errors. Agreement between radiologists on IQ scores for various CT IQ indicators was assessed using weighted kappa. A kappa value above 0.8 was considered as almost perfect agreement, 0.6 to 0.8 as good, 0.4 to 0.6 as moderate, 0.2 to 0.4 as fair and less than 0.2 as poor. Statistical significance was set at a two-sided *P* value of 0.05.

Results

Study group characteristics

The study group consisted of 50 patients (27 male and 23 female) with a mean age of 67.7 ± 13.3 (range 34–89 years). Mean average heart rate for the duration of the scan was 80.32 ± 19.98 bpm (range 30–139). Mean dose length product was 309 ± 188.3 (range 117.9–1228), which converts to a mean dose of 5.25 mSv (weighting factor = 0.017).

Image quality evaluation

The interobserver agreement between the two thoracic radiologists was considered good to almost perfect in each category for the majority of regions, with an average kappa value of 0.79.

Evaluation of clarity of vessels

There was a significant difference in the clarity of vessels between the tagged and untagged data sets, as shown in Table 2. Each anatomical region was assessed as showing better clarity of vessels in the tagged data set. The left lower zone was the anatomical region that showed the largest difference in clarity of vessels between the tagged and untagged data sets, suggesting that ECG gating allows the influence of cardiac motion on the vessels to be reduced further compared with theother anatomical regions assessed. Figure 1 demonstrates the difference in the clarity of vessels between an ECG-tagged data set and its corresponding untagged data set.

Evaluation of clarity of lungs

Table 2 indicates that there was better clarity in the left lower zone only (see Fig. 2), while there was no signifi-

Table 2. Difference between tagged and untagged scores for each image quality indicator

Region	Clarity of vessels	Clarity of lungs	Respiratory motion	Cardiac motion	Artefacts	Low-contrast resolution	Contrast media opacification	Image noise
Left lower zone								
Estimate ± SE	0.41 ± 0.10	0.25 ± 0.10	–0.16 ± 0.10	0.93 ± 0.12	0.11 ± 0.07	–0.55 ± 0.09	–0.13 ± 0.08	–0.50 ± 0.10
P value	≤0.001*	0.02*	0.10	≤0.001*	0.13	≤0.001*	0.09	≤0.001*
Left middle zone								
Estimate ± SE	0.34 ± 0.11	0.12 ± 0.11	–0.06 ± 0.10	0.87 ± 0.11	0.07 ± 0.08	–0.53 ± 0.08	–0.11 ± 0.08	–0.51 ± 0.10
P value	≤0.001*	0.28	0.53	≤0.001*	0.40	≤0.001*	0.15	≤0.001*
Left pulmonary trunk								
Estimate ± SE	0.21 ± 0.08		–0.07 ± 0.05	0.56 ± 0.09	0.01 ± 0.04	–0.50 ± 0.09	–0.09 ± 0.07	–0.47 ± 0.09
P value	0.01*		0.13	≤0.001*	0.80	≤0.001*	0.19	≤0.001*
Left upper zone								
Estimate ± SE	0.25 ± 0.10	0.05 ± 0.09	–0.03 ± 0.07	0.42 ± 0.07	–0.13 ± 0.08	–0.54 ± 0.09	–0.10 ± 0.07	–0.55 ± 0.10
P value	0.02*	0.58	0.65	≤0.001*	0.10	≤0.001*	0.17	≤0.001*
Right lower zone								
Estimate ± SE	0.31 ± 0.10	0.18 ± 0.10	–0.16 ± 0.08	1.15 ± 0.54	–0.04 ± 0.06	–0.52 ± 0.09	–0.13 ± 0.08	–0.49 ± 0.10
P value	≤0.001*	0.07	0.06	0.04*	0.50	≤0.001*	0.09	≤0.001*
Right middle zone								
Estimate ± SE	0.30 ± 0.10	0.11 ± 0.10	–0.05 ± 0.08	0.62 ± 0.09	–0.09 ± 0.07	–0.53 ± 0.08	–0.11 ± 0.08	–0.52 ± 0.10
P value	0.01*	0.26	0.50	≤0.001*	0.17	≤0.001*	0.15	≤0.001*
Right pulmonary trunk								
Estimate ± SE	0.22 ± 0.08		0.08 ± 0.06	0.89 ± 0.10	0.01 ± 0.04	–0.50 ± 0.09	–0.09 ± 0.07	–0.48 ± 0.10
P value	0.01*		0.15	≤0.001*	0.80	≤0.001*	0.19	≤0.001*
Right upper zone								
Estimate ± SE	0.26 ± 0.10	0.03 ± 0.09	–0.05 ± 0.06	0.41 ± 0.07	–0.11 ± 0.08	–0.55 ± 0.09	–0.05 ± 0.09	–0.54 ± 0.09
P value	0.01*	0.74	0.43	≤0.001*	0.15	≤0.001*	0.57	≤0.001*

*$P \leq 0.05$. Positive estimates reflect a swing towards the tagged data series, while negative results reflect a swing towards the untagged data series.

cant difference in the remaining regions of the chest (see Figs. 3 and 4). The left lower zone is the region that is impacted the most by cardiac pulsation.

Evaluation of respiratory motion

There was no significant difference in the respiratory motion between the tagged and untagged data sets in any of the anatomical regions, as shown in Table 2. This result suggests that ECG gating has no effect on the amount of respiratory motion seen in a CTPA examination.

Evaluation of cardiac motion

There was a significant difference in the influence of cardiac motion between the tagged and untagged data sets (shown in Table 2), with the tagged data set

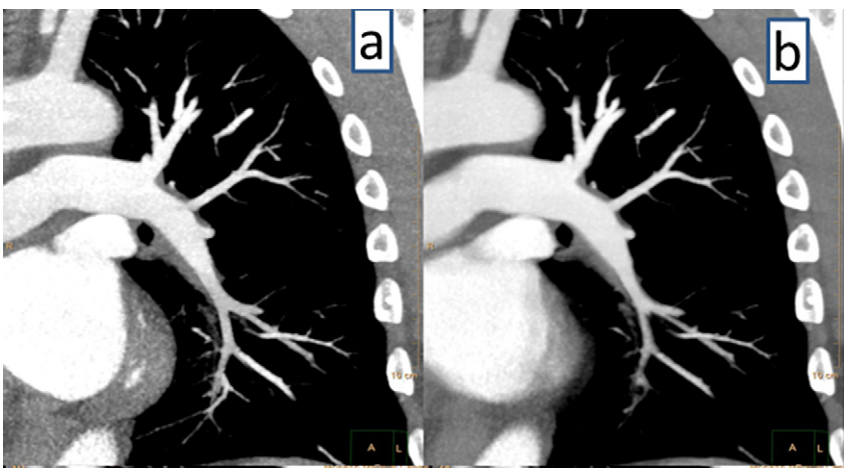

Fig. 1. Oblique image of the left pulmonary arteries showing improved vessel clarity in the ECG-tagged data set (a). The vessel borders are better defined in direct comparison to the non-ECG-tagged data set (b).

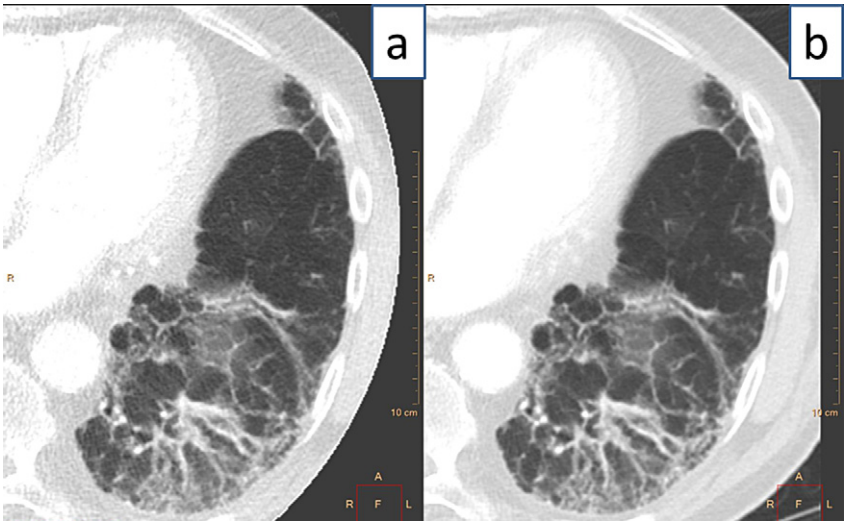

Fig. 2. Axial image of the left lower lobe of the lung showing superior clarity of lung for the ECG-tagged data set (a) in direct comparison to the non-ECG-tagged data set (b).

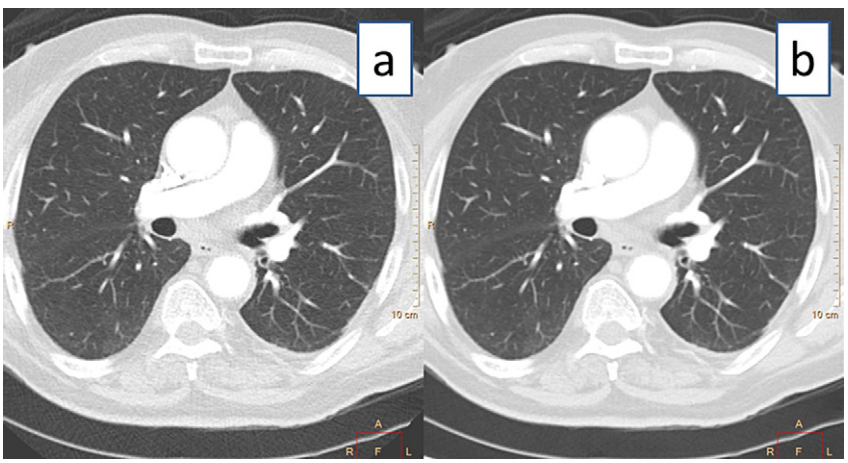

Fig. 3. Axial image of the lungs taken at the level of the right main pulmonary artery showing equal clarity of lung between the ECG-tagged data set (a) and the non-ECG-tagged data set (b).

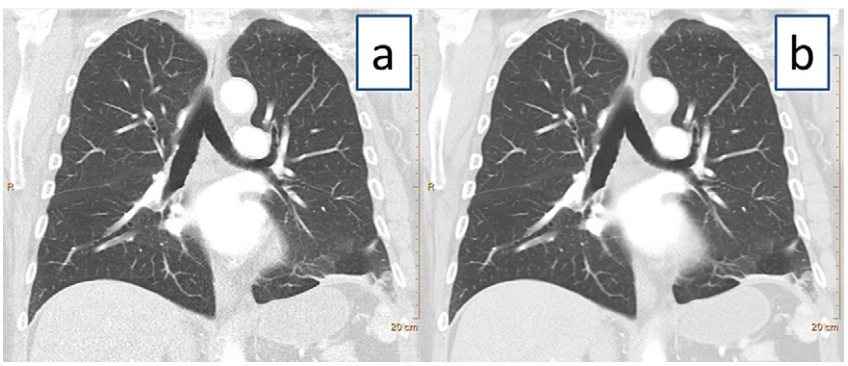

Fig. 4. Coronal image of the lungs showing equal clarity of lung between the ECG-tagged data set (a) and the non-ECG-tagged data set (b).

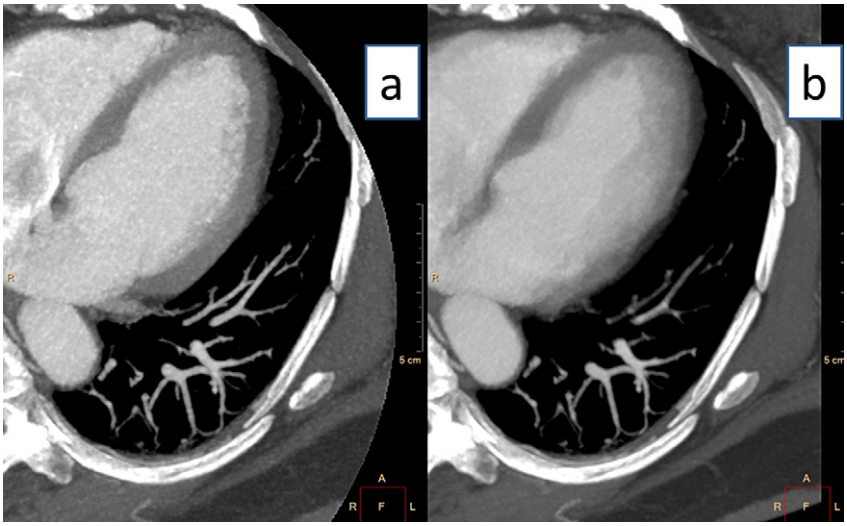

Fig. 5. Axial image through level of the left ventricle showing the effects of cardiac motion. The borders of the heart and surrounding vessels in the ECG-tagged data set (a) are better defined with less influence from cardiac motion than in the non-ECG-tagged data set (b). The average heart rate for this acquisition was 80 bpm.

showing less influence of cardiac motion on image quality in each anatomical region. The difference was particularly noticeable in the lower zones (see Fig. 5).

Evaluation of the presence of other artefacts

There was no significant difference in the presence of artefacts between the tagged and untagged data sets in any of the anatomical regions, as shown in Table 2.

Evaluation of low-contrast resolution

Each anatomical region was assessed as showing better low-contrast resolution in the untagged data set than in the tagged data set (as seen in Table 2), suggesting that ECG gating reduces the low-contrast resolution of images.

Evaluation of contrast media opacification

There was no significant difference in the contrast media density between the tagged and untagged data sets (see Table 2).

Evaluation of image noise

There was a significant difference in image noise influencing IQ between the tagged and untagged data sets, as seen in Table 2. More image noise was seen in the tagged data set than in the untagged data set. This is visually represented in Figures 6 and 7.

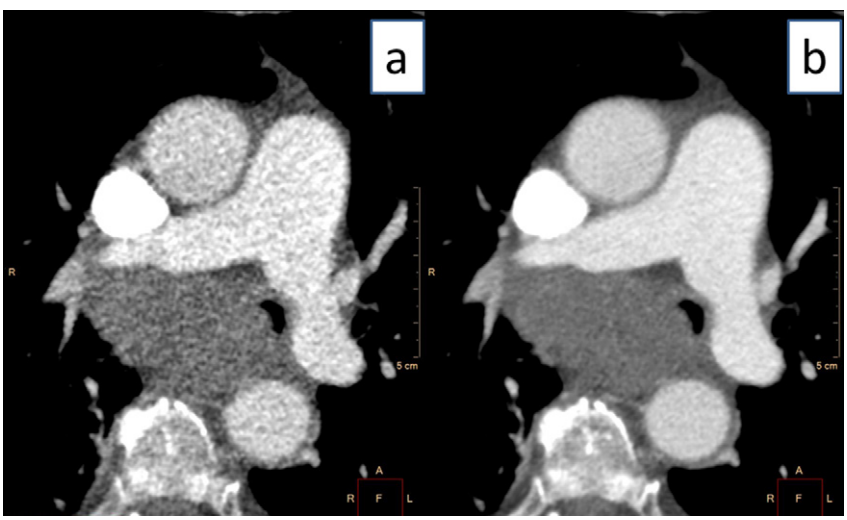

Fig. 6. Axial image through the pulmonary arteries, showing more image noise in the ECG-tagged data set (a) in comparison with the non-ECG-tagged data set (b).

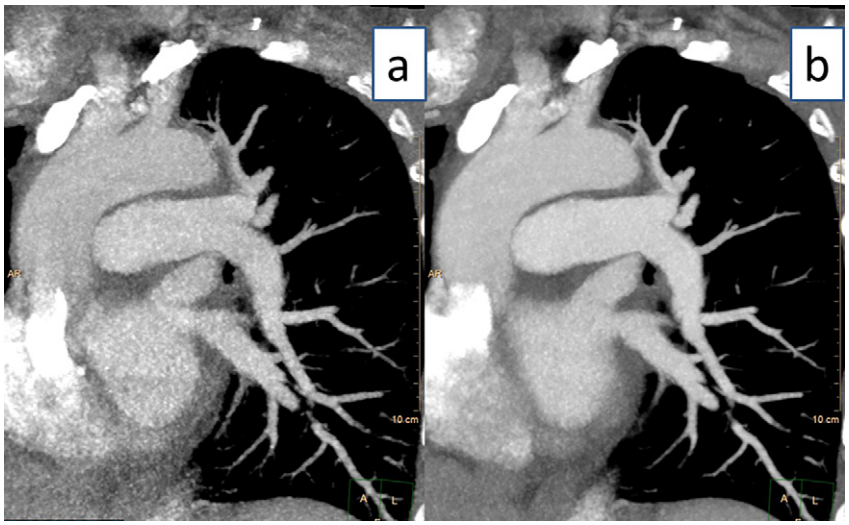

Fig. 7. Oblique image of the left pulmonary arteries, showing more image noise in the ECG-tagged data set (a) in comparison to the non-ECG-tagged data set (b).

Pulmonary embolus detection

Pulmonary emboli were detected in 6 of the 50 examinations; each one was detected on both reconstructed data sets. All the emboli detected were noted to be of moderate to large size.

Discussion

Electrocardiogram gating played a significant role in influencing the overall image quality obtained from the CTPA examinations. It minimised the cardiac and aortic pulsation artefact. Cardiac motion degrades IQ, not only for the details of the lung adjacent to the heart and aorta, but also for the surrounding pulmonary vessels and lung due to double shadows. The reduction in cardiac motion was complemented by an improvement in vessel clarity. Vessel clarity is of high importance in CTPA examinations, as motion artefact makes vessel borders less distinct and may lead to erroneous diagnosis of pulmonary embolism. Electrocardiogram gating particularly enhanced the clarity of the subsegmental branches of the pulmonary arteries in the mediobasal segments of both lower lobes adjacent to the heart borders.

Electrocardiogram gating demonstrated no adverse influences in terms of respiratory motion, contrast media opacification or artefacts. Respiratory motion is primarily influenced by the patient's ability to breath-hold, and ECG gating did not have any impact. Opacification of iodinated contrast media is altered by the X-ray penetration (i.e. 100 kV and 120 kV) and also by the amount of contrast that reaches the pulmonary vessels at the time of scanning; however, the peak kilovoltage was standardised in this study to 100 kVp. Electrocardiogram gating played no role in contrast media opacification.

Image noise and low-contrast resolution were better in non-ECG-tagged data ($P < 0.001$). Electrocardiogram-gated reconstruction is inherently more noisy than non-ECG-gated reconstruction because the data are summed from multiple reconstruction angle sectors from multiple cardiac cycles at a predefined phase point of the ECG cycle. This results in improved temporal resolution but limits the inherent signal in the final image, as smaller angles contain fewer data. Ungated data are reconstructed using a traditional spiral interpolation technique commonly employed in CT reconstruction that disregards ECG correlation. The result is a less noisy image.

Electrocardiogram gating was not found to provide any benefit in detecting PE via CTPA examination; however, the relatively small sample size of 50 patients must be considered. The majority of patients with PE in our sample presented with moderate to large emboli; detecting differences in sensitivity between the two techniques in the detection of emboli that are both small in size and low in number may require considerably larger sample sizes.

One limitation of the study is that the ECG-gated data set was compared with a virtual ungated data set. The virtual ungated data set had a number of differences from actual ungated CTPA examinations, with the main difference being that the pitch used in our study was relatively slow in comparison with routine ungated CTPA. This technique was used to simulate a non-ECG-gated study so that two comparable studies to review could be obtained while only irradiating the patient once. The influence that a slower pitch has on IQ would be highlighted with further comparison between ECG-gated images and routine ungated CTPA images. Due to the slower pitch, a relatively large dose of iodinated contrast media was necessary to accommodate the slower scan time.

Another limitation of our study is that only retrospective ECG gating was analysed in assessing how IQ changed across the chest. Retrospective gating allowed us to obtain an untagged data set to which to compare

our tagged data set. Although there was no increase in the radiation doses administered to patients utilising this technique, a prospectively ECG-gated CTPA examination would potentially render lower doses than those achieved in this study. Prospective gating may increase the potential for presence of stair-step artefact in the *z* direction of the image where the data are not stitched together well. Prospective gating would also have serious consequences for scan time if performed with 4-cm *z*-axis coverage and would be better achieved on a CT scanner with greater *z*-axis coverage. Further expansion of a double-blinded randomised study of prospective ECG-gated and routine CTPA examinations with a bigger patient population may show the benefits of ECG gating with regard to pulmonary vessel clarity.

The aim for CTPA protocol development going forward is to achieve the benefits of ECG gating while minimising the inherent image noise and optimising vessel clarity. Increasing the dose while maintaining other parameters would result in less image noise but more radiation exposure for the patient. Alternatively, altering the iterative reconstruction settings could achieve reduction in image noise without impacting on radiation dose to the patient. This higher level of iteration would result in the desired reduction of image noise. Another alternative would be to reconstruct the data using novel model-based reconstruction techniques (which aim to reduce more noise than the statistics-based iterative reconstruction techniques), and this would result in less image noise and hence achieve the desired results.

Another limitation of the study is that all observations of the data sets were only rated visually, and a quantitative assessment was not undertaken. Quantitative analysis of factors such as noise and contrast opacification may add further information in the future.

Conclusion

We determined that both vessel clarity and cardiac motion improved in the ECG-tagged reconstructions, while image noise and low-contrast resolution were better in non-ECG-tagged reconstructions. Both types of reconstruction data set should be assessed when evaluating CTPA examinations, as they provide complementary information without impacting on radiation dose. Future considerations would be to reconstruct ECG-gated CTPA examinations with less image noise from one data set.

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