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A quality improvement project addressing motion artefact on CTPA in a district general hospital setting: A complete cycle resulting in changed practice

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Abstract

Introduction: A still breath hold from the patient is one of the key requirements for a diagnostic computed tomography pulmonary angiogram (CTPA). It is important for the timely identification and treatment of patients with life threatening pulmonary emboli (PEs). Motion artefact on CTPA can cause blurring, double borders, shading and streaking in the lungs, which can either obscure PEs or create artefact that mimics PEs. This risks patient harm from delayed diagnoses, missed PEs, false positives and extra radiation and contrast exposure due to repeat studies.

Methods: We devised local standards and methodology for assessing the presence and degree of motion artefact on CTs. The study consisted of initial data collection, implementation of changes to clinical practice, and subsequent repeat data collection 3 months after implementation of interventions. For each data collection round, 100 consecutive inpatient and emergency CTPAs performed in a UK District General Hospital were retrospectively identified and images reviewed to categorise each as having either: 'no significant', 'minor' or 'major' motion artefact. There were no exclusions. Interventions after initial data collection included a multidisciplinary meeting with radiographers, department assistants, and radiologists to devise changes to workflow and practices to build in

'rehearsal' of a breath-hold and explanation of breathing instructions with patients before scanning. A prompting phrase for this was added to our CTPA scanning protocol.

Results: Initial results demonstrated that 50% of CTPA showed either minor or major motion artefact, while 50% showed no significant motion artefact. For 2% with minor motion, a clinical reason for why this was unavoidable was provided. Therefore 52% of studies met the proposed local standards. In total, 45% of CTPA were assessed to have minor motion and 5% had major motion artefact (non-diagnostic). 18% of CTPA were positive for PE. Following implementation of changes to practice, repeat data collection demonstrated that 67% of CTPA showed no significant motion artefact. 3% with minor motion provided a clinical reason why this was unavoidable. Therefore 70% of studies met the proposed standard. The increase in compliance with local standards was statistically significant (p=0.00906).

Conclusion: Our interventions improved compliance with local standards from 52% to 70%. We recommend rehearsal of breath-holding with patients before CTPA scans as a quick and easy way to improve the diagnostic quality of scans. A prompting phrase within the CTPA scanning protocol has proven effective.

Introduction

Computed tomography pulmonary angiography (CTPA) has become a standard radiologic modality in most institutions for the evaluation of patients with suspected pulmonary emboli (PEs), given its wide availability, high sensitivity, and high specificity.[1, 2] PEs are potentially life-threatening and require rapid and accurate identification to allow timely treatment. The quality of CTPA studies is therefore important.

A diagnostic quality scan requires adequate pulmonary contrast opacification and breath-holding at ease.[3] Yet prior literature has reported that motion artefact from breathing is frequent.[4] It has been cited as the most common cause for indeterminate studies, followed by inadequate contrast opacification and, less commonly, streak artefact and obesity-related artefact.[5,6]

The effect of motion on lung images is to create blurring, double borders, shading and streaking[7], which can mimic or obscure PEs and lead to misinterpretation. In addition, these problems can hinder the optimal evaluation of lung abnormalities, as well as mediastinal, vascular and skeletal findings.[4]

Poor quality CTPA, such as those with excessive motion, have the potential to result in harm to patients by delaying diagnoses, causing false negatives and false positives, or exposing the patient to extra radiation and contrast when a scan has to be repeated.[1] This will tend to occur in patients who are critically ill, unconscious, unable to follow instructions, or those with persistent cough, shortness of breath or chest pain limiting their breath-holding ability.[8] However, we have observed anecdotally at our institution that not all scans with motion artefact are from patients within this cohort. Patients with hearing or visual

impairments, for example, may show reduced compliance.[9] Those who are anxious or who for any reason may be less able to take in instructions can also show reduced compliance.

The cardiac CT is another investigation for which the quality of the study is contingent on minimising breathing motion.[10] Although there are multiple differences between cardiac CTs and CTPA, (including patient cohort, medications administered, fields of view, cardiac gating, for example) one common factor is an explanation and instruction to the patient about breath-holding at ease. It is also an easily modifiable factor in the process. During cardiac CT preparation at our institution the patient is asked to rehearse breath-holding in order to determine the likely heart rate during the procedure, but this appears to have the added benefit of preparing them for this action during the scan. However, there is not the same discussion prior to CTPA at our institution, despite the same requirements for the patient.

In this study, we aim to assess the presence and degree of motion artefact on CTPA, quantify the number of non-diagnostic scans and repeat scans, and implement strategies to improve image clarity by minimising patient motion.

Methodology

The Quantitative Standards

To the best of our knowledge, there are no published standards for acceptable levels of motion artefact on CTPA. For this quality improvement project (QIP), we have therefore devised local standards for what is acceptable in terms of motion artefact on CT images.

The QIP standard devised for this study:

“There should be no significant motion artefact on lung images or alternatively the reason for unavoidable motion is documented by the scanning radiographer”.

The definition of “no significant motion artefact” (and also “minor” and “major” motion artefact) and the methods used to assess this are described below.

The target for compliance was set at 97%.

Methods

This study employed two stages: a preliminary evaluation of prevalence of motion artefact (round 1 data collection) prior to implementation of changes in practice and a new evaluation three months after implementation (round 2 data collection).

For each round of data collection, 100 consecutive inpatient and emergency department CTPA performed at a UK District General Hospital were retrospectively identified using the Trust’s electronic Radiology Information System (RIS). There were no exclusion criteria. The sample size of 100 was chosen as a pragmatic value balancing timescale and level of confidence in the data. A prior power calculation determined that at least 76 scans would be

required in each sample to demonstrate an improvement of from 75% to 97% compliance, as an estimated example. Patients were scanned on either the GE Optima 660 or GE Discovery GSI CT scanner. A standard scanning technique was followed with a 20-gauge cannula or larger used to inject 70mls of Omnipaque™ 350 contrast intravenously via pump injector at 4mls per second. The scan was threshold triggered at the pulmonary trunk and a helical acquisition acquired.

Pseudonymized data were recorded in a Microsoft Excel® 2016 spreadsheet and included patient demographics, comorbidities, scan technique, the presence and degree of motion artefact in the lungs, comments left by Radiographers, the necessity for a repeat scan within 24 hours, and the final Radiologist report, including whether the scan was positive or negative for PEs and any Radiologist comments on diagnostic adequacy.

The image stack for each CTPA was viewed on a DICOM screen using PACS (Picture Archiving and Communication System) software. The entirety of the lungs were appraised in a lung window (Centre: -498, Width: 1465) by the Consultant Radiologist reporting the scan (experience varied from 3 to more than 30 years), a second Consultant Radiologist (4 years of Consultant experience) and a Junior Doctor (equivalent to a junior resident apply for radiology) reviewing for motion artefact for this study. By consensus, the scans were categorized as having either “no significant motion artefact”, “minor motion artefact” or “major motion artefact”.

“No significant motion artefact” was defined as: “No breathing or movement that impedes accurate assessment of the pulmonary arterial tree to a subsegmental level (e.g. no blurring or double borders). Minor motion at the extreme apices or bases or related to cardiac motion (e.g. in the lingula) is acceptable within this statement” (Figure 1).

Figure 1. No significant motion artefact.

"Minor motion artefact" was defined as: "Easily visible motion artefact that impedes accurate assessment of the pulmonary arterial tree down to subsegmental level in one or more areas" (Figure 2).

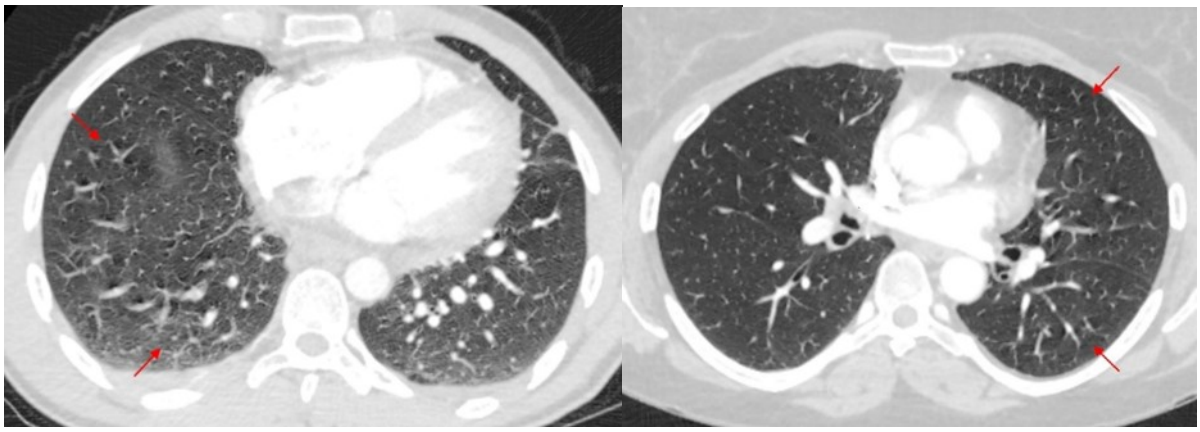

Figure 2. Minor motion artifact. Example axial CT images in lung window settings. Red arrows indicate examples of motion artefact.

"Major motion artefact" was defined as: "Motion artefact that significantly distorts images and makes the scan non-diagnostic for anything other than central saddle pulmonary emboli" (Figure 3).

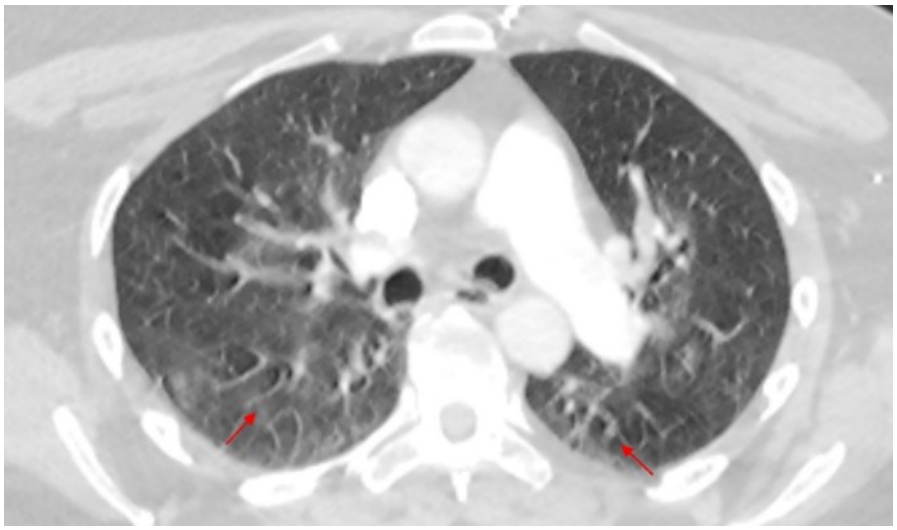

Figure 3. Major motion artifact. Example axial CT image in lung window settings. Red arrows indicate examples of motion artefact.

Interventions

Following the first round and prior to the second round of data collection, interventions were made which resulted in altered clinical practice. A multidisciplinary meeting was held with the trust's radiographers, radiology department assistants (RDAs) and radiologists. The initial results were presented to the team and there was education on the clinical importance of a still breath-hold for producing a diagnostically adequate scan. After discussion, several changes in practice and reminders were agreed (Table 1).

Table 1. Changes in practice and reminders for the radiology team

Implemented changes in practice	Reminders of good practice
• The professional explaining a CTPA scan to a patient facilitates rehearsing the breath-hold component before scanning • A prompting phrase was incorporated into the CTPA protocol on the RIS	• Use provided pictorial cues for patients with hearing impairment • Adjust in-scanner voice instruction volume if necessary • Document the reason(s) for any suboptimal scans on the RIS

We proposed a small, easily achievable change in practice whereby the professional explaining the scanning process also emphasises and rehearses the breath-hold element with the patient before their scan. The multidisciplinary team felt it would be achievable and would not add any time to their preparations, as they usually converse with the patients while cannulating and positioning them. We implemented the addition of a prompting phrase: "Rehearse breath-hold with the patient before the scan" to the CTPA scanning protocol which is auto-populated when a Radiologist authorises a CTPA request in the RIS. The use of pictorial prompts for deaf patients and other ways to facilitate communication where this is challenging were also discussed and emphasised. The volume of the in-scanner voice instructions was discussed. The importance and value of documentation from the radiographer about the patient's state and ability to comply was also emphasised. More documentation of this sort was encouraged, given that it can aid in scan interpretation and in discussions about subsequent imaging.

Analysis

Data analysis was performed using formulas within the Excel® spreadsheet. Descriptive statistics, such as totals and percentages, were used. A z-test was used to assess whether compliance with the standards or the percentage of cardiorespiratory comorbidities differed significantly between round 1 and round 2 populations in the two sets of data collected. $p<0.05$ was considered significant.

Ethical considerations

This retrospective quality improvement project did not require prior approval from an ethics committee, as per the Health Research Authority online decision tool for NHS Research.

Results

For the first round of data collection, 100 acute CTPA were performed between 20th September 2022 and 25th October 2022. For all 100 scans a standard scanning technique was followed (20-gauge cannula or larger to inject 70mls of Omnipaque™ 350 contrast intravenously via pump injector at 4mls per second). There were 2 instances of contrast extravasation (2%).

The ratio of male to female patients was 39:61 (39 men, 61 women). The mean patient age was 66.91 years (range: 24 – 102 years). 78% (78/100) of patients were described in the

imaging referral as having one or more cardiovascular or respiratory comorbidities – 27% (27/100) of patients had only cardiovascular comorbidities (e.g., hypertension, acute coronary syndrome, heart failure), 23% (23/100) of patients had only respiratory comorbidities (e.g., asthma, chronic obstructive pulmonary disease, obstructive sleep apnoea), and 28% (28/100) of patients had both cardiovascular and respiratory comorbidities (Figure 4).

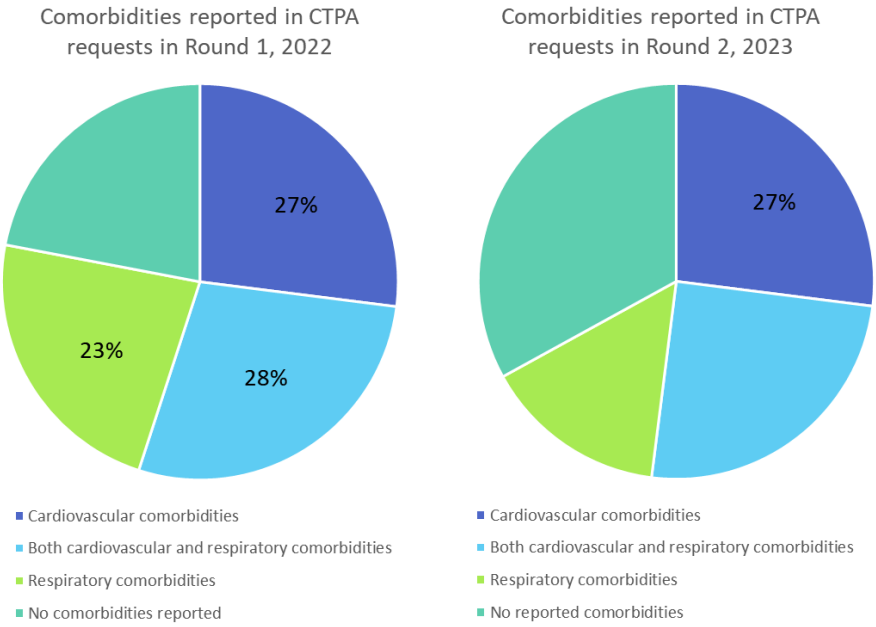

Figure 4. Patient comorbidities in Round 1 and Round 2 of data collection

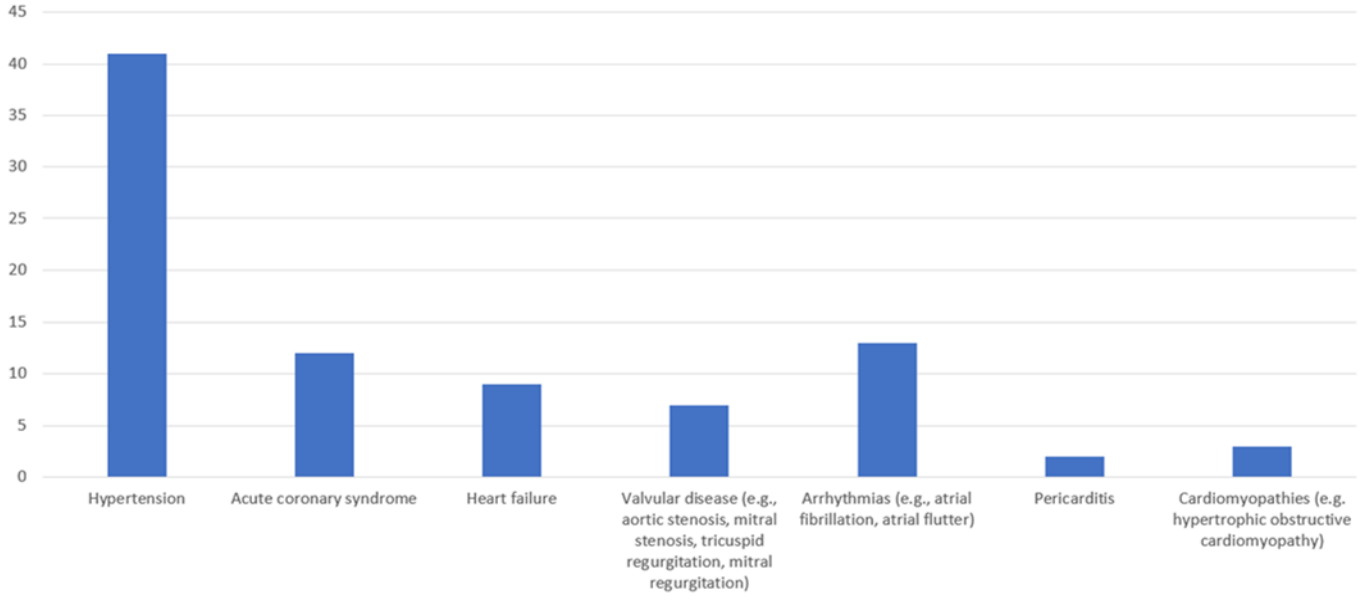

Figure 5. Cardiovascular comorbidities in Round 1 of data collection

Of those with cardiovascular comorbidities in this round, the most common comorbidity was hypertension, followed by cardiac arrhythmias and previous acute coronary syndrome (ACS) (Figure 5); of those with respiratory comorbidities, the most common comorbidity was

asthma, followed by chronic obstructive pulmonary disease (COPD) and obstructive sleep apnoea (OSA) (Figure 6). 18% (18/100) of CTPA were positive for PE, according to the radiologists' report.

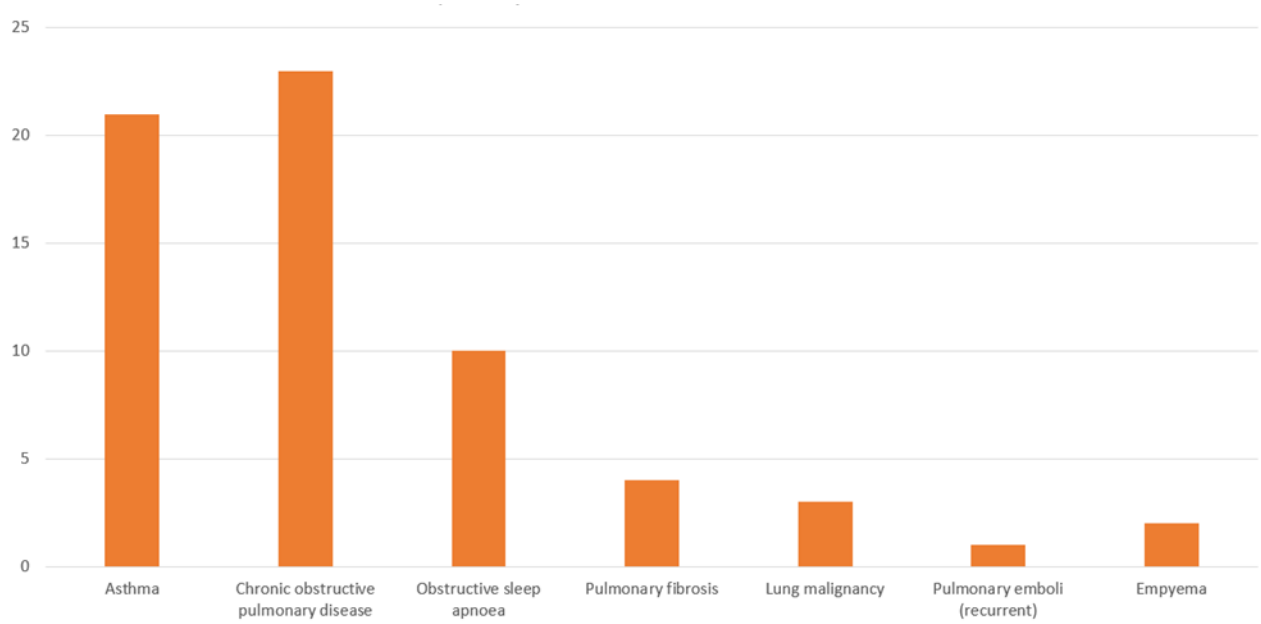

Figure 6. Respiratory comorbidities in Round 1 of data collection

Consensus review of lung images on all scans revealed that 50% (50/100) scans showed no significant motion artefact and 50% showed either minor or major motion artefact (Figure 7). Of those with motion artefact, 10% (5/50) were of the major category, defined as being non-diagnostic for any emboli other than central saddle PEs, and 90% (45/50) were minor. 2/45 studies with minor motion artefact included a comment from the radiographer as to why this was unavoidable. In one instance the patient was unconscious and unable to comply with breathing instructions and in the other, there was an extravasation of contrast causing the patient to move their whole body. Therefore 52% (50+2/100) of studies met the QIP standard. This figure is below the target of 97%.

4 scans were repeated in the same sitting, or within 24 hours of the first scan – 3 of which were due to suboptimal arterial contrast opacification, and the other due to adjacent venous contrast possibly causing beam attenuation. No repeat scans were performed for motion artefact alone.

More than 3 months after implementation of the changes, a second round of data collection and analysis was performed. 100 consecutive acute CTPA performed between 16th June 2023 and 18th July 2023 were identified and analysed using identical methodology.

The standard scanning technique, as already described, was again followed. There was one recorded instance of extravasation of contrast. The ratio of male to female patients was 45:55. The mean patient age was 63.06 years (range: 21 – 91 years). 67% (67/100) of patients were described in the imaging referral as having one or more cardiovascular or

respiratory comorbidities – 27% (27/100) of patients had only cardiovascular comorbidities, 15% (15/100) of patients had only respiratory comorbidities, and 25% (25/100) of patients had both cardiovascular and respiratory comorbidities (Figure 2). Of those with cardiovascular comorbidities in this round, the most common comorbidity was hypertension, followed by cardiac arrhythmias and previous ACS (Figure 7); of those with respiratory comorbidities, the most common comorbidity was asthma, followed by COPD and lung malignancy (Figure 8).

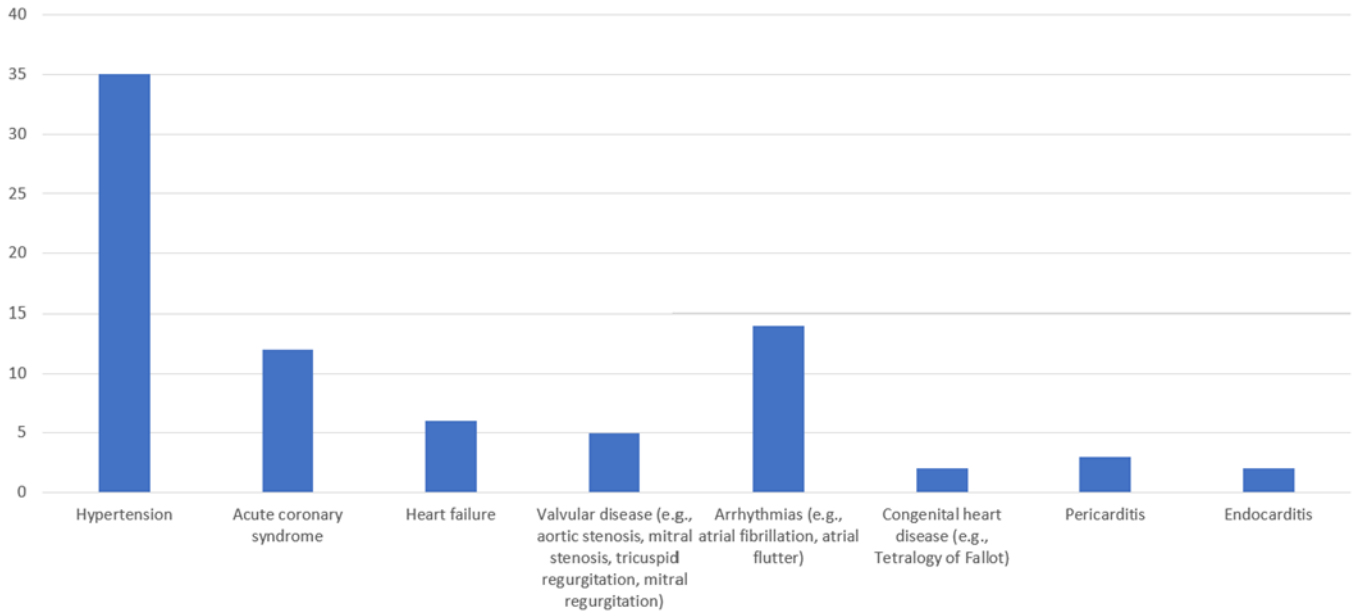

Figure 7. Cardiovascular comorbidities in Round 2 of data collection

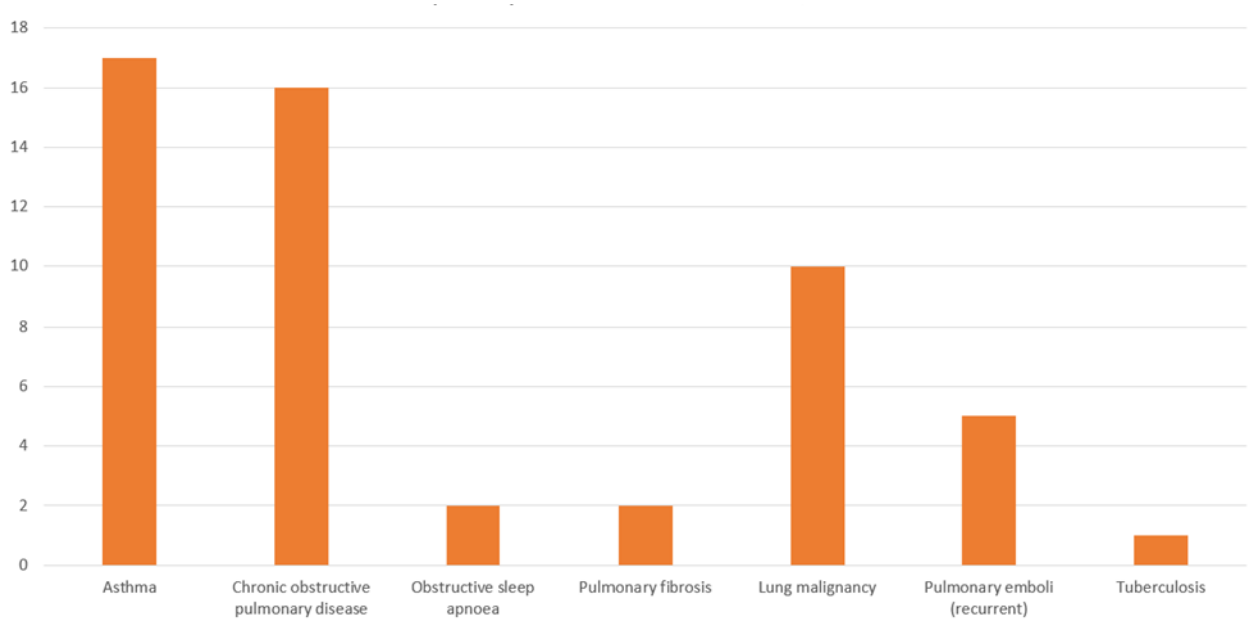

Figure 8. Respiratory comorbidities in Round 2 of data collection

A z-test was used to determine if there was a significant difference between the percentage of patients with reported cardiorespiratory comorbidities in round 1 (78%) versus round 2 (67%) of data collection. This gave a z value of 1.742 (p=0.08186), suggesting the difference is not statistically significance.

16% (16/100) of CTPA were positive for PE, according to the Radiologist's report.

Consensus review of lung images revealed that 67% (67/100) scans showed no significant motion artefact and 33% showed minor motion artefact (Figure 9).

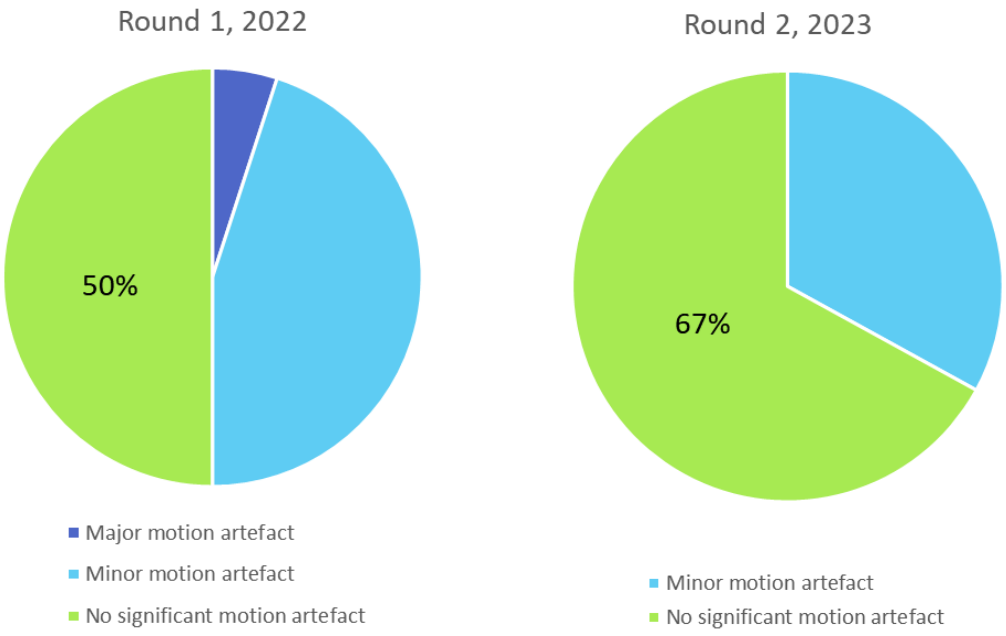

Figure 9. Motion artefact on lung images for acute CTPA by consensus opinion

Of those with motion artefact, none were of the major category. 3/33 studies with minor motion artefact included a comment from the radiographer as to why this was unavoidable. In one instance the patient was confused, in another the patient was unconscious and intubated, and in another there was a small extravasation of contrast resulting in movement. Therefore 70% (67+3/100) of studies met the QIP standard after implementation of changes. There were no repeat scans performed in this round.

A z-test was used to determine if there was a significant difference between compliance with the QIP standard between the round 1 population (52% compliance) and the round 2 population (70% compliance). This gave a z value of -2.6095 (p=0.00906), suggesting a statistically significant difference.

Discussion

Between the first and second QIP rounds, compliance with local standards for motion on CTPA improved from 52% to 70%, which was a statistically significant difference (p=0.00906). There was a reduction in 'major' motion artefact from 5% overall to 0%. This suggests that the changes implemented and the multidisciplinary educational meeting

around this were effective, although there remains room for improvement. The compliance continues to fall short of the 97% target.

The percentage of 'major' motion artefact found in the first round of data collection is in a similar range to that previously published, for example 8/403 (2%) non diagnostic scans due to motion artefact in one paper.[4] The rates of positivity of scans for pulmonary emboli of 18% and 16% in first and second rounds respectively meets the Royal College of Radiologist's (RCR) target on AuditLive for between 15.4 – 37.4% CTPA positive pick-up rate.

Other groups have previously reported in the literature the effect of cardiac gating on CTPA image quality, but found no significant difference in breathing motion artefact overall, with only a reduction in motion in the left lower lobe beside the heart seen.[11] Others report comparability of image quality between breath-holding and free-breathing techniques with newer generation CT technology using larger detector arrays, dual-source CT, ultrafast acquisition times and/or iterative or deep-learning reconstructions.[12,13,14,15] However, there are no published studies to our knowledge investigating the specific effect of rehearsing breath-holding with patients on the CTPA images produced. It has been reported that instructing patients to breath-hold 'at ease' is superior to asking for a deep inspiration for pulmonary arterial contrast opacification (so this formed part of the instructions for patients in this study).[3] However in the described study the exclusion criteria included 'marked movement and breathing artefacts due to the patients' non-adherence to instructions'[3] so the effect on motion artefact was not formally assessed by the authors.

The main change in practice that was introduced here evolved from observation of cardiac CT scans, where patients are asked to 'rehearse' breath-holding before the scan to determine likely heart rate during breath holds.[10] Anecdotally this appeared to reduce breathing motion artefact on the lung reformat images, although it should be noted that there are multiple other differences in the two investigations which may also contribute. As an easily achievable modification with no anticipated negative effects, it was implemented as a trial.

Multiple different factors may affect whether there is breathing motion on a CT scan. Patient factors include: level of consciousness, mental capacity, memory, understanding of what is being asked of them, physical ability to comply at that time (e.g. breathlessness, pain, comorbidities) and ability to see or hear instructions.[8,9] Staff factors include: clarity of explanation, anticipation of problems and mitigation. Scanning factors include: clarity and volume of recorded breath-holding instructions on the scanner, background scanner noise, facility of pictorial prompts, scanning time, scanner speed, size of detector array, and contrast-related complications such as extravasation.

This QIP changed practice in modifiable areas (staff explanation, actions, and documentation) and educated the wider team on the other (non-modifiable) factors that may contribute to breathing motion artefact. It is evident that many patient factors, such as

consciousness and breathlessness, for example, cannot be modified within Radiology to improve scans. Similarly, scanner factors were not changed within the scope of this project.

As a surrogate marker of non-modifiable patient factors, we recorded patient age and cardiorespiratory comorbidities. There was a slight age reduction between QIP rounds, with mean age 66.91 years in the first round and 63.06 years in the second. There was also a slight reduction in comorbidities, with 78% recorded in the first round and 67% in the second round, although this was not statistically significant. The types and ratios of comorbidities remained similar between the two rounds. Although, the recording of comorbidities was based on information provided by the referrer and the inclusion and breadth of this varies widely, so this may not be completely accurate.

Given the significant level of improvement in compliance with the standard between rounds (52% to 70% overall, with major motion reducing from 5% to 0%), we surmise that both the change to practice we introduced and the slight difference in patient factors played a role in the improved results, the latter likely having a much lesser impact.

Ad hoc documentation did not significantly change between the 2 rounds. We asked the CT scanning team to document when they felt that there were factors contributing to excess motion on the scan. This was documented for 2/50 scans in the first round and 3/33 scans in the second round. The reason for excess motion is important both when interpretating the scan and making decisions about further imaging and in determining if further improvements can be made at subsequent QIP rounds.

Limitations

As already discussed, the slight differences in patient demographics between the two samples collected are a potential limitation when compared to other studies with age-matched and comorbidity-matched cohorts, although this was beyond the scope of the project. Another limitation is the relatively small sample size (100 scans per round), although this sample size was derived pragmatically and after a power calculation suggesting a minimum sample size of 76. However, at future reassessment of compliance, a new power calculation and revised sample size are recommended. The subjective nature of the assessment of motion artefact is also a potential limitation, with the possibility of introducing bias or error. To mitigate this, two Consultant Radiologists and one Junior Doctor participated in motion artefact assessment and a consensus view was recorded. In future it may be possible with the use of artificial intelligence to objectively measure motion, as has been reported in the literature[4], although this was not available for this project.

The future impact of breathing motion on the diagnostic adequacy of CTPAs should also be considered in light of technological advances, as it is may become less important. As really came to the fore during the Covid-19 pandemic, newer generations of CT scanner with larger detector arrays, dual-source, ultrafast acquisition times and iterative or deep-learning reconstructions allow faster imaging of the chest which reduces the impact of breathing on

the images acquired.[12,13,14,15] Although these techniques have limitations and drawbacks also, but are emerging as potentially very useful for patients with dyspnoea.

It is also noted that none of the 4 CTPAs repeated in this study were repeated for motion artefact alone, with other reasons such as suboptimal contrast opacification and beam hardening artefact cited as the rationale for repeating. It is not clear whether the lack of repeat scanning for excess motion is because it was considered futile or because the scan was deemed adequate to answer the clinical question. Although likely to become less important with technological advances in CT scanning, a still breath hold at ease will remain desirable for the best quality scan, in our opinion.

Conclusion

We recommend rehearsal of breath-holding with patients before CTPA scans as a quick and easy way to improve stillness of breath-holding and reduce motion artefact on scans. It improved compliance with local standards for breathing motion artefact from 52% up to 70% at our institution. We utilised a prompting phrase in the auto-populated CTPA protocol on the RIS as a reminder. This has proven effective, although there remains scope for further possible improvement, especially in ad hoc documentation of useful observations made in the Radiology department.

Statements and Declarations

Competing Interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

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References

1. Hayes SA, Soff GA, Zabor EC, Moskowitz CS, Liu CC, Ginsberg MS. Clinical consequences of an indeterminate CT pulmonary angiogram in cancer patients. Clinical Imaging. 2014 Sept;38(5):637–40. doi:10.1016/j.clinimag.2014.04.015
2. Schönfeld T, Seitz P, Krieghoff C, Ponorac S, Wötzel A, Olthoff S, et al. High-pitch CT pulmonary angiography (CTPA) with ultra-low contrast medium volume for the detection of pulmonary embolism: A comparison with standard CTPA. European Radiology. 2023 Sept 1;34(3):1921–31. doi:10.1007/s00330-023-10101-8
3. Li YJ, Lau KK, Ardley N, Lau T. Efficacy of 'breath holding at ease' during ct pulmonary angiography in the improvement of contrast enhancement in pulmonary arteries. Journal of Medical Imaging and Radiation Oncology. 2013 Mar 4;57(4):415–22. doi:10.1111/1754-9485.12039

4. Dasegowda G, Bizzo BC, Kaviani P, Karout L, Ebrahimian S, Digumarthy SR, et al. Auto-detection of motion artifacts on CT pulmonary angiograms with a physician-trained AI algorithm. Diagnostics. 2023 Feb 18;13(4):778. doi:10.3390/diagnostics13040778

5. Remy-Jardin M, Pistolesi M, Goodman LR, Gefter WB, Gottschalk A, Mayo JR, et al. Management of suspected acute pulmonary embolism in the era of CT angiography: A statement from the Fleischner Society. Radiology. 2007 Nov;245(2):315–29. doi:10.1148/radiol.2452070397

6. Jones SE, Wittram C. The indeterminate CT pulmonary angiogram: Imaging characteristics and patient clinical outcome. Radiology. 2005 Oct;237(1):329–37. doi:10.1148/radiol.2371041520

7. Barrett JF, Keat N. Artifacts in CT: Recognition and avoidance. RadioGraphics. 2004;24(6):1679–91. doi: 10.1148/rg.246045065.

8. Varchetta F, Cosson P, Widdowfield M, Danzi R, Orlando G, Natale M, et al. Chest CT in patients with shortness of breath: Comparing high pitch CT and conventional CT on respiratory artefacts and dose. Radiography. 2021 Aug;27(3):908–14. doi:10.1016/j.radi.2021.02.013

9. Lichtenstein MJ. Hearing and visual impairments. Clinics in Geriatric Medicine. 1992 Feb;8(1):173–82. doi:10.1016/s0749-0690(18)30505-6

10. Zhang J, Fletcher JG, Harmsen WS, Araoz PA, Williamson EE, Primak AN, et al. Analysis of heart rate and heart rate variation during cardiac CT Examinations. Academic Radiology. 2008 Jan;15(1):40–8. doi:10.1016/j.acra.2007.07.023

11. Ardley ND, Lau KK, Buchan K, Paul E and Troupis JM. Effects of electrocardiogram gating on CT pulmonary angiography image quality. Journal of Medical Imaging and Radiation Oncology. 2014;58(3):303-311. Doi: 10.1111/1754-9485.12147

12. Cantarinha A, Bassil C, Savignac A, Devilder M, Maxwell F, Creze M, et al. “Triple low” free-breathing CTPA protocol for patients with dysnoea. Clinical Radiology. 2022 Aug;77(8):e628-e635. Doi: 10.1016/j.crad.2022.05.007

13. Bunch PM, Fulwadhva UP, Wortman JR, Primak AN, Madan R, Steigner ML, et al. Motion artefact reduction from high-pitch dual-source computed tomography pulmonary angiography. Journal of Computer Assisted Tomography. 2018 Jul/Aug;42(4):623-629. Doi: 0.1097/RCT.0000000000000736

14. Bauer RW, Schell B, Beeres M, Wichmann JL, Bodelle B, Vogl TJ, et al. High-pitch dual-source computed tomography pulmonary angiography in freely breathing patients. Journal of Thoracic Imaging. 2012 Nov;27(6):376-381. Doi: 10.1097/RTI.0b013e318250067e

15. Ajlan AM, Binzaqr S, Jadkarim DA, Jamjoom LG and Leipsic J. High-pitch helical dual-source computed tomography pulmonary angiography: comparing image quality in inspiratory breath-hold and during free-breathing. Journal of Thoracic Imaging. 2016 Jn:31(1): 56-62. Doi: 10.1097/RTI.0000000000000173