The utility of chest radiography in predicting the diagnostic quality of Computed Tomography Pulmonary Angiography (CTPA).

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Purpose

The purpose of this study is to evaluate whether the radiological findings on a chest radiograph performed prior to CTPA can predict the likelihood of a suboptimal CTPA due to respiratory motion artifact. We hypothesize that in patients with severely abnormal chest radiographs; demonstrating pulmonary edema, moderate-to-large pleural effusions or lobar collapse, there is a significant increase in the likelihood of suboptimal CTPA due to respiratory motion artifact. Confirmation of this hypothesis should help the acute care physician to make an informed decision regarding the likely utility of CTPA in the acute care setting for these patients.

Pulmonary embolism (PE) is a common condition with an estimated annual incidence of 0.5 to 1 in 1000\(^1\). Clinical suspicion requires prompt diagnosis as untreated PE has a mortality rate approaching 30\%\(^2\) reduced to less than 8\% with treatment\(^3\).

Technological advances, availability and utility of the technique have made Computed Tomographic Pulmonary Angiography (CTPA) the investigation of choice for suspected PE in most centres\(^4\), replacing conventional catheter angiography as the reference gold-standard\(^5\). CTPA has documented high diagnostic accuracy\(^6\) with sensitivity and specificities of 83\% and 96\% respectively\(^7\).

The accuracy of CTPA is dependant on optimal pulmonary artery opacification and minimisation of artifacts\(^8\). However, patients who present with dyspnoea have considerable difficulty in arresting respiration even for the few seconds that a current generation Multi Detector Computed Tomography (MDCT) scanner takes to acquire the examination. This results in an increased incidence of indeterminate or suboptimal CTPA studies especially due to respiratory motion artifact, the most common cause for suboptimal CTPA studies\(^9\).

Patients with PE present with a variety of non-specific cardio-respiratory symptoms and chest radiography is recommended as the initial imaging investigation to investigate alternative diagnoses to account for the patient's symptoms including pneumonia, pulmonary oedema and pneumothorax\(^10\).
Materials and Methods

Retrospective cohort study of 1031 consecutive CTPA examinations performed from January 2007 to April 2010 in a large university teaching hospital. Approved by the institutional research ethics board, individual patient consent was not required. Electronic patient records were analysed to determine patient demographics, source of patient referral for CTPA examination; inpatient, outpatient or emergency department, and whether a chest radiograph was performed within 6 hours prior to CTPA.

Imaging protocols

All CTPA studies were performed using a standard protocol on the same equipment; 64 detector row CT scanners (Aquilion 64, Toshiba Medical Systems Ltd, Tokyo, Japan). An 18G intravenous cannula was placed in the antecubital fossa and 75-85cc iodixanol 320mg/ml (Visipaque, GE Healthcare, Toronto, Canada) was injected at 5-6cc/sec using a power injector (Medrad Spectris, Medrad, Pittsburgh, US). The X-ray exposure factors (tube kilovoltage, tube current, and gantry rotation speed) were adjusted to patient body habitus. Helical acquisitions were performed in a single breath-hold using automated bolus-tracking with a threshold-trigger of 150HU in the main pulmonary artery. Scan acquisition was performed from lung apex to base.

Image evaluation

All chest imaging studies at our institution are read by sub-speciality trained chest radiologists with at least 8 years' experience of reporting chest radiographs and CTPA studies. The radiology reports of all the chest radiographs were graded according to severity of findings. We modified a previously described grading scale used to classify pulmonary edema\textsuperscript{11} as in table 1:

<table>
<thead>
<tr>
<th>Grading</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>Mild</td>
<td>Vascular redistribution, linear atelectasis, mild fibrosis, mild consolidation, small pleural effusion</td>
</tr>
<tr>
<td>Moderate</td>
<td>Interstitial edema, moderate pleural effusion, moderate consolidation</td>
</tr>
<tr>
<td>Severe</td>
<td>Alveolar edema, extensive consolidation, large pleural effusion, lobar collapse.</td>
</tr>
</tbody>
</table>
Table 1. Severity grading of chest radiographic abnorespiratory motion artifacts.

CTPA reports were categorized as either clearly positive or negative for PE or indeterminate. The indeterminate category included all studies reported as suboptimal or equivocal. All were re-read by a sub-speciality trained staff radiologist with 17 years' experience of chest imaging and re-categorized as necessary.

A CTPA was classified as suboptimal if there was no demonstrable PE and failure to adequately demonstrate any artery to a segmental level. The cause of a suboptimal study was recorded as either due to patient factors, respiratory motion artifact or technical factors; suboptimal exposure due to a mismatch between X-ray tube parameters and patient body habitus, or due to poor opacification of the pulmonary arteries, including a contrast density of <300HU in the main pulmonary artery (mPA) and an aorta to mPA contrast density ratio of >1. The CTPA was classified as positive for PE if one or more low density filling defects were demonstrated within opacified pulmonary arteries to a sub-segmental level. The study did not review any other findings on CTPA including alternative diagnoses.

Statistical analysis

Descriptive statistics were used to summarize the demographic and clinical characteristics of the study population, overall and by chest radiography findings. Logistic regression models were used to further examine the association between key factors (sex, visit type, age, severity of abnormality on chest radiograph) and CTPA suboptimal status; odds ratios and 95% confidence intervals were generated. Analyses were performed using statistical software Statistics Package for the Social Sciences (SPSS) Statistics 17.0 (SPSS for Windows 2008, SPSS Inc, Chicago, IL).
Results

During the study period 1031 patients were referred for CTPA. Fig 1 summarises the patient demographics and Figure 2 the main study findings. 324/1031 (31%) of patients had a chest radiograph performed within 6 hours of CTPA; the patient cohort comprised 6% outpatients, 31% inpatients and 63% emergency department patients (Figure 3).

This patient group formed the study cohort whose demographics are also shown in figure 1. Of 816 inpatients and emergency department patients, 509 (62%) did not have a chest radiograph performed within 6 hours of CTPA.

202 (62%) patients had an abnormal chest radiograph. 55 (27%) were graded as mildly abnormal and 80 (40%) as moderately abnormal. Of the 67 (33%) patients with severe radiographic abnormalities, all but 2 patients were inpatients or emergency department patients. A total of 190 patients presented acutely and had chest radiography performed within 6 hours of CTPA, of these 65 (34%) had severe abnormalities on chest radiography.

In total there were 120 (11.6%) suboptimal CTPA studies. The number of suboptimal studies increased with acuity of presentation; 13 (6%) of outpatients, 38 (9.9%) of inpatients and 69 (14.7%) of emergency department patients had suboptimal studies. Respiratory motion artifact was responsible for suboptimal CTPA studies in 85 (71%) of patients, suboptimal X-ray exposure in 28 (23%) of patients, and sub-optimal arterial opacification in 7 (6%) of patients (Figure 4).

In patients who had a prior chest radiograph within 6 hours of CTPA, a higher incidence of respiratory motion artifact was noted in those with abnormal chest radiographs (76%) compared to those with normal chest radiographs (61%). The proportion of suboptimal CTPA studies due to respiratory motion artifact increased with increased severity grading of chest radiographic abnormalities (Figure 5).

The likelihood of having a suboptimal CTPA was significantly higher in males and acutely ill patients (Figure 6) and increased by 1% with each year of age. Patients with severe abnormalities on chest radiography had the highest odds ratio (OR) of having a suboptimal CTPA (OR 2.12, 95% CI 1.02, 4.43) compared with patients with no chest radiographic abnormality.

The overall incidence of PE in our study population was 20% (185/911). There were 97 males and 88 females with a mean age of 61.1 years (range 19-91 years). The incidence
of PE in this study cohort varied from 23% of outpatients, 17% of inpatients and 16% of emergency department patients (Figure 2). The incidence of PE in patients who did not have chest radiography in the 6 hours prior to CTPA was 21% (136/643) comparable to the incidence in our study cohort.
Fig. 1: Patient demographics. ED = emergency department patient, OP = outpatient, IP = inpatient.

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Fig. 2: Flow chart summarising the utility of chest radiography (CXR) in the 6 hours preceding CT pulmonary angiography (CTPA) and the influence of the result of CXR on diagnostic quality of the CTPA.

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### Fig. 3: The patient cohort stratified by visit type and chest radiograph status. CXR = chest radiograph. PE = pulmonary embolism.

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<table>
<thead>
<tr>
<th></th>
<th>No CXR 64/708 (9%)</th>
<th>Normal CXR 18/122 (15%)</th>
<th>Abnormal CXR 38/202 (19%)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency</td>
<td>46 (72%)</td>
<td>11 (61%)</td>
<td>28 (76%)</td>
<td>85 (71%)</td>
</tr>
<tr>
<td>Inpatient</td>
<td>54</td>
<td>82</td>
<td>19</td>
<td>155</td>
</tr>
<tr>
<td>Outpatient</td>
<td>144</td>
<td>102</td>
<td>49</td>
<td>295</td>
</tr>
</tbody>
</table>

### Fig. 4: The relationship between chest radiograph status and etiology of suboptimal computed tomography pulmonary angiography (CTPA). CXR = chest radiograph

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**Fig. 5:** The relationship between chest radiograph status and etiology of suboptimal computed tomography pulmonary angiography (CTPA). CXR = chest radiograph

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<table>
<thead>
<tr>
<th>Variable(s)</th>
<th>Odds ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sex</strong></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>1.00</td>
</tr>
<tr>
<td>Male</td>
<td>1.70 (1.16, 2.50)</td>
</tr>
<tr>
<td><strong>Visit type</strong></td>
<td></td>
</tr>
<tr>
<td>ED</td>
<td>1.00</td>
</tr>
<tr>
<td>OP</td>
<td>0.37 (0.20, 0.69)</td>
</tr>
<tr>
<td>IP</td>
<td>0.71 (0.46, 1.08)</td>
</tr>
<tr>
<td><strong>Age (years)</strong></td>
<td>1.01 (1.00, 1.02)</td>
</tr>
<tr>
<td><strong>Severity of CXR abnormality</strong></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>1.00</td>
</tr>
<tr>
<td>Mild</td>
<td>0.58 (0.20, 1.65)</td>
</tr>
<tr>
<td>Moderate</td>
<td>1.33 (0.63, 2.83)</td>
</tr>
<tr>
<td>Severe</td>
<td>2.12 (1.02, 4.43)</td>
</tr>
</tbody>
</table>

**Fig. 6:** Influence of study variables on odds ratio of suboptimal computed tomography pulmonary angiography (CTPA). CXR = chest radiograph, ED = emergency department patient, OP = outpatient, IP = inpatient

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Conclusions

In conclusion, this study has identified that an abnormal chest radiograph predicts an increased likelihood of suboptimal CTPA due to respiratory motion artifact and the risk is doubled in patients with chest radiograph evidence of moderate to large pleural effusions, moderate to severe pulmonary edema, pneumonia, or lobar collapse. In patients with suspected acute PE the pretest probability should be assessed and consideration given to alternative diagnoses. A chest radiograph should be the first imaging test as it may yield an alternative diagnosis, and as we have demonstrated helps to predict the quality of subsequent CTPA. Careful consideration should be given to treating conditions that may be responsible for the patients’ symptoms, prior to performing a CTPA to rule out PE. If the treating physician remains concerned about the possibility of underlying PE in patients that demonstrate moderate to large pleural effusions, moderate to severe pulmonary edema, pneumonia, or lobar collapse; clearly the CTPA needs to be performed. However, we propose that the patient should be advised that there is a higher risk of an indeterminate CTPA study due to co-existing medical conditions.

The chest radiograph is an important diagnostic tool in patients with suspected PE. Although there are pathognomonic features of PE on chest radiography\textsuperscript{12,13}, these occur relatively infrequently\textsuperscript{14}. The principal role of the chest radiograph is to exclude alternative diagnoses that may mimic the presentation of PE; this is important because the majority of patients referred for CTPA do not have underlying PE to explain their symptoms\textsuperscript{15}. In this study, we have demonstrated that the severity of radiographic abnormalities predicts the likelihood of a suboptimal CTPA due to respiratory motion artifact. This highlights an important triage role for the chest radiograph in selecting appropriate patients for CTPA, a role that has not been fully appreciated or utilized.

Patients referred for CTPA with moderate to large pleural effusions, moderate to severe pulmonary edema, pneumonia, or lobar collapse on chest radiography; have twice the odds ratio of an indeterminate CTPA, principally due to respiratory motion artifact, compared to patients with normal chest radiographs. Respiratory motion artifact is the main cause of non diagnostic CTPA studies and the incidence increases with the acuity of patient presentation. This is concerning due to the significant increase in utilization of CTPA by acute care physicians\textsuperscript{16}, and raises an interesting ethical dilemma. If a clinician wishes to exclude PE but the chest radiograph demonstrates any of the severe abnormalities that indicate a higher likelihood of an indeterminate CTPA study, should the CTPA be performed? We suggest the patient should be informed of the increased risk of a suboptimal study and the possibility of needing alternative strategies, such as leg doppler ultrasound, if the CTPA is suboptimal. Alternatively, if the possibility of PE is felt
to be less likely given the appearances on chest radiography; the patient could be treated for the demonstrated abnormalities and then reassessed for the likelihood of having a PE.

The clinical presentation of PE is non-specific. There are well validated clinical prediction rules for PE diagnosis\textsuperscript{17,18}, though their utilization among acute care physicians is variable\textsuperscript{19}. Serological tests, including D-Dimers assays, can be used to stratify the risk for thromboembolic disease\textsuperscript{20} but these become non specific with underlying medical conditions\textsuperscript{21} and testing in patients with high clinical probability is not helpful. Clinicians are therefore reliant on imaging, particularly with CTPA, in many patients. The reported effective patient radiation exposure from a CTPA study is 8.4-9.7mSv which is relatively high for a thoracic CT study and is of concern for potential carcinogenesis\textsuperscript{15}. Although recent advances in CT technology have resulted in significant reductions in patient radiation dose\textsuperscript{22}, given the combination of a high likelihood of a negative study, a relatively high effective patient radiation dose and the significant increase in risk of a suboptimal study with severe abnormalities on chest radiography, it is suggested that the referring clinician should at least inform the patient of the increased possibility of a non diagnostic CTPA study if the chest radiograph demonstrates these findings.

Despite the importance of the chest radiograph in patients with suspected PE and departmental guidelines that advocate chest radiography prior to CTPA, this study highlights the low utilization of chest radiography within 6 hours prior to CTPA. Multiple factors influence the timing of a clinician’s request for a CTPA and the actual performance of the CTPA, yet 62% of inpatients and emergency department patients did not have a chest radiograph performed within 6 hours of the CTPA study. Other studies have found similarly poor utilization of chest radiography prior to CTPA. A retrospective study of Medicare records demonstrated that only 50% of patients with positive PE diagnosis identified as an inpatient had chest radiography performed as part of the diagnostic workup\textsuperscript{23}. Our data demonstrates a higher utilization of chest radiography for emergency department patients (57%), presumably as these patients are new admissions with no recent imaging studies. The number of inpatients with chest radiography 6 hours prior to CTPA was surprising low (less than 25%), presumably as these patients had prior chest imaging during their admission. However, we did not specifically evaluate this data as we had arbitrarily defined a limit of 6 hours between chest radiography and CTPA as a reasonable time period during which any significant abnormalities related to the patients’ presenting symptoms would be demonstrated on chest radiography and would likely correlate with CTPA findings.

34% of inpatients and emergency department patients had a chest radiograph categorized as severely abnormal. These are the patients in whom CTPA is most likely to be suboptimal and in whom chest radiography is strongly advocated. Image degradation
in these patients was mainly due to difficulty in maintaining the short breath hold required
for CTPA, an absolute pre-requisite of optimal CTPA technique\textsuperscript{8}. This confirms the
findings from previous studies that have identified respiratory motion artifact as the
most frequent cause of a suboptimal CTPA\textsuperscript{9}. Other factors such as suboptimal arterial
opacification were also important contributors accounting for 21-27\% of suboptimal
scans in this patient cohort irrespective of the appearance on chest radiography. This
highlights the importance of patient coaching, careful optimization of scan protocols and
ultrafast image acquisition whilst performing CTPA.

Although the study cohort focused on patients who had chest radiography within 6-hours
of CTPA, we also analyzed the CTPA findings in patients with no recent chest radiograph.
The incidence of PE in this patient population was similar to the overall incidence of PE
in the study cohort and there was no significant difference in the incidence of respiratory
motion artifact in the CTPA studies of these patients. These observations suggest that
there was no systematic bias in determining which patients had chest radiography prior
to CTPA. However, we did not perform detailed analyses investigating why patients did
not have recent chest radiography or the time interval between chest radiography being
ordered to a study being performed in patients with suspected PE.

The overall rate of suboptimal CTPA examinations in this study (more than 10\%) was
higher than that found by other authors\textsuperscript{24}; we believe that the principal reason for this is
the larger number of inpatients and emergency department patients in our study cohort.
However, the rate of suboptimal CTPA examinations in our outpatient population (6\%)
correlates with predominantly outpatient-based studies\textsuperscript{24}.

The rate of PE diagnosis was 20\%. The incidence of PE in the emergency department
and inpatients was 16\% and 17\% respectively, and it was slightly higher in the ambulatory
outpatient population. This compares to the findings in similar studies\textsuperscript{24,25}. Although the
rates of PE for inpatients and emergency department patients is comparable to that of
other studies\textsuperscript{15}, the PE rate in our study for outpatients (23\%) is considerably higher
possibly because of the large proportion of oncology patients treated at our institution.

The study is limited by a retrospective design and the use of study reports to
categorize the chest radiographs and CTPA studies. None of the chest studies that
were categorically reported as either demonstrating or excluding PE were re-reviewed.
However, all chest studies performed at our institution are reported by sub-specialty
trained thoracic radiologists with a minimum of 8 years’ experience in reporting chest
radiographs and CTPA studies and all of the indeterminate studies were re-reviewed
by a chest radiologist with more than more than 17 years of reporting chest imaging
studies. In addition, we did not analyze the correlation between chest radiography and
CTPA for pleural and parenchymal abnormalities as this was not the objective of this
study. This study has not taken into account body habitus; however X-ray exposure for
chest radiography and CTPA is adjusted for patient body habitus in order to optimize image quality and patient radiation dose. Although a CTPA scan was classified as suboptimal if any segmental vessel was inadequately opacified, the study could still provide useful clinical information regarding the opacified pulmonary arteries and non-vascular pathology not assessed in our study.

The past decade has witnessed a dramatic increase in the number of CTPA scans performed and to some this seems beyond the scope of medical necessity\textsuperscript{26}. An increase in the rate of PE diagnosis without a change in mortality either suggests more effective treatment or over-diagnosis of a less fatal spectrum of PE\textsuperscript{27,28}. It is understandable that there is increased focus regarding the appropriate role of CTPA in patients with suspected PE\textsuperscript{29}. Our study strongly supports the use of chest radiography as an accessible triage tool in patients with suspected PE and one that is under-utilized.
References


