Breath-hold at ease: a method of improving the diagnostic quality of CT pulmonary angiogram

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Purpose

Pulmonary embolism (PE) is one of the most common causes of deaths in patients with all age groups. It has an incidence rate of 1 in 1000 patients [1] with mortality rate as high as 30% [2,3,4]. PE diagnosis has moved from conventional pulmonary angiography to computed tomographic pulmonary angiography (CTPA) in recent decades [5-16]. CTPA has been regarded as an accurate and safe test to diagnose pulmonary embolism [7-9,11]. It has a sensitivity of 60 - 80% and specificity of 90-100% [5,6]. A relatively high percentage (5 -6%) of CTPA has been deemed inconclusive or technically insufficient [10,16] due to motion/breathing artefacts and poor contrast enhancement of pulmonary arteries [Figure 1], which affect 74% and 40% of CTPA respectively [16].

The poor contrast enhancement of the pulmonary arteries is related to the too early or delayed peak contrast enhancement [17]. CTPA scan is conventionally performed after patient has been asked to take a full inspiration and then breath-hold. The deep inspiration immediately prior to the commencement of the CT scanning may give rise to 'transient interruption of contrast' (TIC) [18, 19] with contrast in the right heart being diluted by the sudden surge of unopacified blood from inferior vena cava. We believe the valsalva effect associated with breath-holding after deep inspiration may lead to decreased cardiac output in some patients delaying the peak contrast enhancement of pulmonary arteries. The combined effects may adversely impact the optimal contrast enhancement of pulmonary arteries leading to suboptimal images.

Our institution has been performing CTPA examinations with the patients being instructed to breath-hold at ease immediately prior to and during the scanning with the aim of removing the potential adverse effects of transient interruption of contrast from deep inspiration and the Valsalva effect from breath-holding after deep inspiration since September 2010. The aim of this retrospective study was to evaluate the efficacy of 'breath-holding at ease' on the contrast enhancement improvement of the pulmonary arteries in the CTPA examinations.
Methods and Materials

All consecutive CTPA studies between January and March 2011 with patients being instructed to breath-hold at ease and all consecutive CTPA studies between January and March 2010 with patients being given conventional instructions of taking deep inspiration and breath-hold were retrospectively reviewed. Patients of all age, gender and body size who had contrast CTPA studies for the pulmonary embolism (PE) exclusion were included. The CTPA studies with marked motion/breathing artifacts, contrast being injected through the Peripherally Inserted Central Catheter (PICC), presence of haemodynamically significant stenosis at the central veins, known history of severe cardiac failure or severe tricuspid and pulmonary valvular disease in patients' history, PE not the primary reason or lung/mediastinal malignancy obstructing the pulmonary arteries were excluded.

All CTPA studies were conducted using a 64-detector row CT scanner (GE LightSpeed VCT XT™, Milwaukee, USA, 2007) with a 64 x 0.625mm detector configuration. Scanning parameters were 100kVp, 150-715mA, 0.4 seconds rotation time and 0.984 pitch. 75mls of Iohexol 350mg/ml was injected via a peripheral intravenous cannula (20-gauge or larger) in a speed of 4mls/second via the contrast injector. Bolus tracking function was used and set at the level of the pulmonary trunk approximately 1-2cm below the carina of the trachea.

The images of all the CTPA scans were randomly reviewed on Picture Archiving and Communication System (PACS) by two blinded readers. Contrast densities in Hounsfield unit (HU) using largest possible region of interests (ROI) at pulmonary trunk, main pulmonary arteries, proximal pulmonary artery branches, right atrium and ascending aorta were measured by 2 blinded readers. Pulmonary embolism, co-existing lung diseases and other pathology were also recorded. Upper abdominal girths were measured on CT.

A statistical analysis was performed on the obtained data, with a mean contrast density in HU and 95% confidence interval calculated for each group. Results of the two groups were then compared using the student's t-test, with a p-value of <0.05 classified as statistically significant. Inter-rater agreement between two blinded raters was calculated using Cohen’s kappa coefficient.
Results

124 patients in total were retrospectively reviewed.

In the 'deep inspiration and breath-hold' group, there were 51 patients (24 female; 27 male; mean age of 65 years; mean upper abdominal girth of 103 cm). 38 patients (74.51%) had negative scan and 11 patients (21.57%) had positive scan. 2 patients (3.92%) had inconclusive scan that were due to suboptimal contrast enhancement. 73 patients (34 female; 39 male; mean age of 62 years; mean upper abdominal girth of 106 cm) were at the 'breath-hold at ease' group. 63 of these patients (86.3%) had negative scan and 6 patients (8.22%) had positive scan. Patients' characteristics were statistically similar between the 2 groups. There were no patients with known history of moderate to severe cardiac failure.

Four patients from 'deep inspiration and breath-hold' group were excluded due to severe motion/breathing artifact. Two patients from 'breath-hold at ease' group were excluded due to contrast being injected through PICC in one patient [Figure 2] and central venous stenosis in another patient [Figure 3]. No patient with severe breathing artifact was seen in the 'breath-hold at ease' group.

6 patients (13%) in the 'deep inspiration and breath-hold' group had contrast densities in pulmonary trunk less than those in the right ventricle and ascending aorta [Figure 1] This was not observed in patients in the 'breath-hold at ease' group.

Suboptimal contrast enhancement with contrast density of less than 200HU was found in 15.6% (8 patients) in the CTPA with 'deep inspiration and breath-hold' group, compared to 2.8% (2 patients) in the CTPA with 'breath-hold at ease' group. Mean contrast enhancement at different anatomical locations of pulmonary arteries, including pulmonary trunk, main pulmonary arteries and proximal branches of pulmonary arteries measured in HU in the 'deep inspiration and breath-hold' group ranged from 320HU to 337HU. In the 'breath-hold at ease' group, the corresponding density measurements were from 375HU to 401HU. There were 16.31% to 19.38% relative improvements in contrast density at different levels of pulmonary arteries. In the 'deep inspiration and breath-hold' group, the mean contrast density of all pulmonary arteries was calculated as 327HU (95% CI: 315HU - 339HU, kappa score of 0.95), whereas in the 'breath-hold at ease' group, the corresponding mean contrast density was 390HU (95% CI: 381HU - 399HU, kappa score of 0.93). There is a 17.95% overall increase (p-value <0.0001) in contrast enhancement in the 'breath-hold at ease' group compared to the traditional 'deep inspiration and breath-hold' group [Table 1]
38% patients in 'deep inspiration and breath-hold' group and 42% of patients in 'breath-hold at ease' group had active lung diseases, including consolidation, atelectasis, bronchogenic carcinoma, pulmonary metastases, marked interstitial lung disease or emphysema. Contrast enhancement in patients with active lung diseases (excluding PE) showed lower contrast densities in pulmonary arteries with mean HU of 307, compared to 325 in normal group for those patients in the 'deep inspiration and breath-hold group'. There were similar phenomenon observed for the 'breath-hold at ease' group, with mean HU of pulmonary arteries of 390HU in patients with active lung disease and 419HU in patients with no lung disease. Patients with active lung disease and without lung disease (excluding PE) also showed a mean 27.04% (p-value of 0.0013) and 28.92% (p-value of 0.0244) improvement in contrast density of pulmonary arteries respectively in the 'breath-hold at ease' group as compared to the 'deep inspiration and breath hold' group [Table 2,3].
Images for this section:

**Fig. 1:** Post contrast CTPA image in coronal reconstruction in a 65 year old male demonstrated suboptimal contrast enhancement of pulmonary arteries with contrast densities in superior vena cava, right heart and aorta being much higher than that in the pulmonary arteries.

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**Fig. 2:** Post contrast CTPA image in coronal reconstruction in a 74 year old male demonstrated a PICC line (arrow) in the central vein through which the IV contrast was injected. This led to poor contrast enhancement of the pulmonary arteries.

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Fig. 3: Post contrast CTPA image in coronal reconstruction in a 53 year old male demonstrated a right subclavian stenosis (arrow) slowing the contrast flow which resulted in poor contrast enhancement of the pulmonary arteries.

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Table 1: Table 1 Mean contrast Hounsfield unit in pulmonary arteries between 'Deep inspiration and breath-hold' group and 'Breath-hold at ease' group.

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Table 2: Mean contrast Hounsfield unit in pulmonary arteries between 'Deep inspiration and breath-hold' group and 'Breath-hold at ease' group in patients with no active lung disease

Table 3: Lung diseased group (excluding PE)
**Table 3:** Mean contrast Hounsfield unit in pulmonary arteries between 'Deep inspiration and breath-hold' group and 'Breath-hold at ease' group in patients with active lung disease

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Conclusion

Inconclusive CTPA results and poor images in general affect the clinician's ability to make confident treatment plans for patients.

There is a decrease in contrast density in the pulmonary arteries 3-5 seconds after patient taking a full inspiration during CTPA scan because of the 'transient interruption of contrast' (TIC) phenomenon, which occurs in 25% to 50% CTPA scans [18]. The appearance of TIC may sometimes mimic pulmonary embolism and lead to false positive CTPA. After the deep inspiration, patients tend to perform valsalva manoeuvre involuntarily when being asked to hold the breath prior to the scanning [19,20]. Valsalva manoeuvre can cause an increase in the intrathoracic pressure leading to decreased blood filling of both right and left ventricles, and consequently lowering the cardiac output [20] and delaying peak contrast opacification of the pulmonary arteries. Therefore, both TIC and Valsalva effect related to patient's deep inspiration and then breath-hold prior to CTPA scanning would reduce the contrast enhancement of the pulmonary arteries at different phases of CTPA scanning. Asking patients not to fully inspire and breath-hold, but halt the breathing at ease, would potentially reduce these adverse effects on contrast density and improve the contrast optimization in the pulmonary arteries.

In this study, there was no noticeable degradation of the image quality of the lung parenchyma, even though the lung volumes were not fully expanded.

Those patients with large area of active lung disease tended to have lower contrast enhancement in pulmonary arteries. Explanation for this would be the regional hypoxic vasoconstriction [21] which lead to increased pulmonary vascular resistance, and therefore decreased blood flow in the pulmonary arteries.

Having patients breath-holding at ease during scanning could potentially help to minimize the breathing artifact as it is not uncommon for individuals to start slowly expiring during scanning when they are holding the breaths at their full lung vital capacity.

The limitation of our study was the relatively small sample size. Co-existing cardiovascular and chest conditions could impact on the contrast density in the pulmonary circulation as seen in some of our patients. Our patients were not stratified into different disease group. A randomized prospective study with a larger sample size and stratification of patients into groups of different underlying medical conditions, cardiovascular and respiratory conditions will help to further assess the beneficial effect of CTPA scanning with patients breath-holding at ease.
In conclusion, scanning with patients breath-holding at ease was shown in our study to have beneficial effect of improving contrast density in the pulmonary arteries, and therefore, the diagnostic quality of the examination. This technique may also help to reduce breathing artifact.


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