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ORIGINAL ARTICLE

The use of computed tomography pulmonary angiography in the diagnosis of heart failure in the acute setting

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Abstract

Background Heart failure is a clinical diagnosis characterised by non-specific symptoms such as dyspnoea, fatigue and oedema. The aim of this pilot study was to investigate what role computed tomography pulmonary angiography could play in supporting a diagnosis of heart failure when a pulmonary embolism has been excluded.

Methods This was a prospective study using the National Integrated Medical Imaging System to assess the potential of computed tomography pulomary angiography (CTPA) as a diagnostic test for heart failure. Consecutive patients were collected from three hospitals of the University of Limerick Hospital Group. We reviewed 230 consecutive CTPA results for cardiac and lung features. Of these, we confirmed which had heart failure by comparison with brain natriuretic peptide (BNP) and echocardiogram criteria. Exclusion criteria included any patients with a diagnosis of pulmonary embolism.

Results Of these 230 patients, only 24 (10.4%) had both objective and clinical signs of heart failure. The most specific signs were shown to be left ventricular enlargement, left atrial enlargement and right ventricular enlargement, which approximated a specificity of 100% (CI 66.3–100.00%). CTPA was shown to match gold standard echocardiography closely in detecting abnormalities as per chi square; Right ventricular enlargement (value = 5.426 $P = 0.02$), left atrial enlargement (value = 4.9 $P = 0.027$) and left ventricular enlargement (value = 5.692 $P = 0.017$).

Conclusion Findings on CTPA which included left ventricular enlargement, left atrial enlargement and right ventricular enlargement were shown to be specific for a diagnosis of heart failure. CTPA should be used by physicians awaiting echocardiography to help guide treatment in cases of suspected heart failure.

Keywords Computed tomography · Heart failure · Pulmonary angiography

Introduction

Heart failure is a clinical syndrome characterised by the following symptoms: dyspnoea at rest or on exercise, fatigue, tiredness and peripheral oedema in combination with signs typical of heart failure (tachypnoea, pulmonary crackles, tachycardia, pleural effusion, raised jugular venous pressure, oedema, hepatomegaly). To confirm a diagnosis of heart failure, there needs to be objective evidence of a structural abnormality of the heart at rest (such as an abnormality on the echocardiogram or a raised brain natriuretic peptide (BNP) concentration) as per European Society of Cardiology (ESC) guidelines [1]. However, it can be challenging to obtain objective measures such as a brain natriuretic peptide (BNP) result or echocardiogram immediately in the acute setting. In our institutions, University Limerick Hospital Group, 24-h access to acute echocardiography is not available, and obtaining a BNP result generally takes several hours for the laboratory to process. Objective findings of heart failure are required for a diagnosis as per ESC criteria (Fig. 1); we propose that radiology may be useful for this purpose, in cases where computed tomography pulmonary angiography (CTPA) imaging has recently been performed. If CTPA is useful to diagnose heart failure, in situations where a patient has already obtained a CTPA to rule out pulmonary embolus prior to echocardiography, physicians should review the CTPA images to aid them in the early diagnosis of heart failure.

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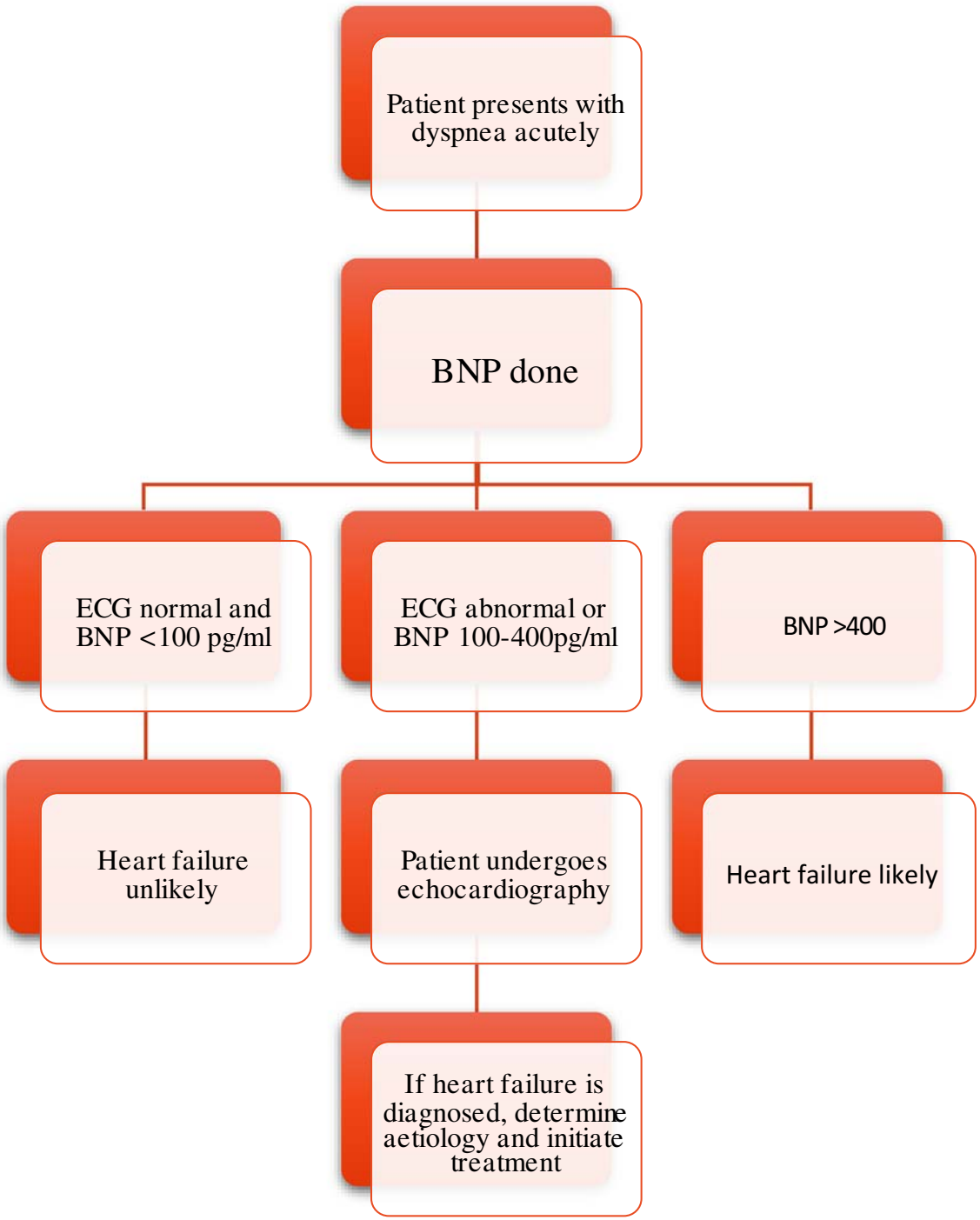

Fig 1 Objective signs of heart failure as per ESC criteria

Methods

Patients collected for this study were from three hospitals in the west of Ireland. The National Integrated Medical Imaging System (NIMIS) was used to identify patients for the study. The search function was used to obtain 230 consecutive patients who had undergone a CTPA (Fig. 2). All patients who undertook CTPA were for the indication 'to rule out a pulmonary embolus' or similar wording. The pre-probability score of patients undergoing CTPA to rule out pulmonary embolus was equivalent to a Wells' score of 2 or a pre-probability test score of 2. Approval was sought as to the collection of data from the local ethics committee in the University Hospital Limerick. The cohort all had a CTPA requested in order to rule out a pulmonary embolus as per hospital protocol. Patients who were diagnosed with a

Fig. 2 Breakdown of CTPA population as categorised by the presence of heart failure

pulmonary embolus were excluded from the study. CTPA was chosen as the modality as the often CTPA is used solely as a method to rule out pulmonary embolus, and other abnormalities are often not clinically utilised. In order to identify patients with heart failure, we used ESC criteria to confirm which of our patients had heart failure which will be discussed below. A normal CTPA is shown in Fig. 3, while one with a pulmonary embolus is shown in Fig. 4. The CTPA images were reported by consultant radiologists, and the reports were subsequently analysed for features of heart failure. These features included left ventricular hypertrophy (Fig. 5), pericardial effusion (Fig. 6), pleural effusion (Fig. 7), reflux of contrast (Fig. 8), enlarged pulmonary arteries and/or aorta (Figs. 9 and 10), right ventricular hypertrophy (Fig. 11), left ventricular

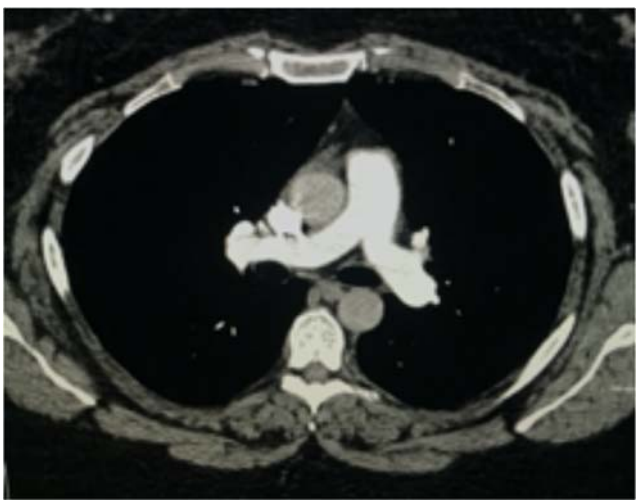

Fig. 3 Normal CTPA

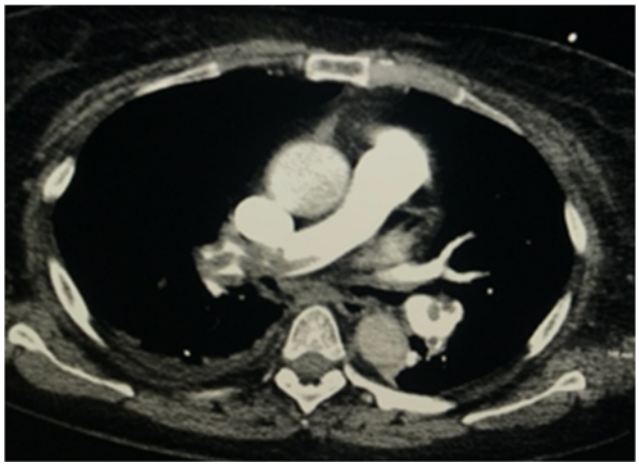

Fig. 4 Pulmonary embolus

hypertrophy (Fig. 12) and ascites (Fig. 13). Cardiomegaly was defined as CTR measures the width of the cardiac silhouette and the thoracic cavity; a ratio greater than 0.5 is an abnormal finding. Enlarged right atrium was defined as an area of above 10–18 cm^2. Enlarged right ventricle was defined if the size of the right ventricle (RV) approximates that of the left ventricle (LV) or if the RV forms the apex and is larger than the LV. Left atrium enlargement was defined as a left atrial anterior-posterior (AP) diameter of above 4 cm. Left ventricular enlargement was defined when the maximum luminal diameter of the LV is greater than 5.6 cm. These are objective signs of heart failure on CTPA as per previous studies [2–4]. Of these, we then evaluated which of these patients had a recent echocardiography report (within 3 months of having a CTPA). This was determined to be a suitable time period, as previous studies showed that echocardiography does not vary significantly within a 1-year period and [5]. Notably the median time between echocardiography and CTPA was 2 weeks. Objective evidence of heart failure were based on ESC

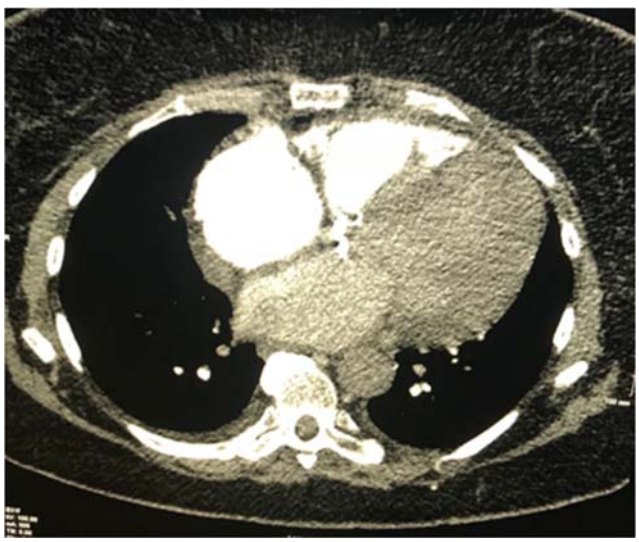

Fig. 5 Left ventricular hypertrophy as seen on CTPA

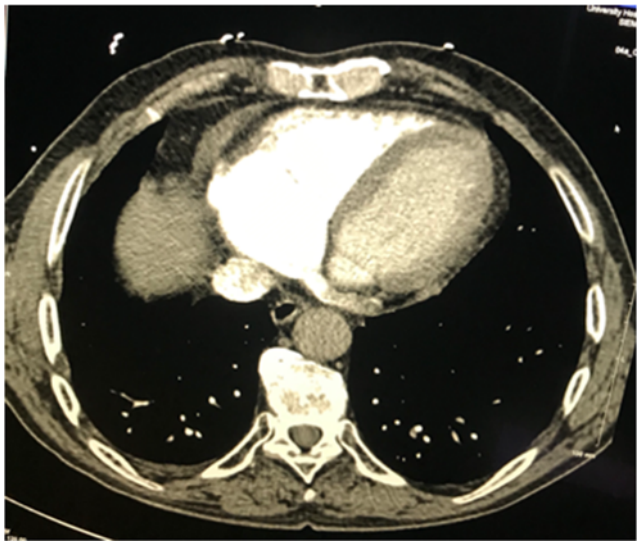

Fig. 6 Pericardial effusion as seen on CTPA

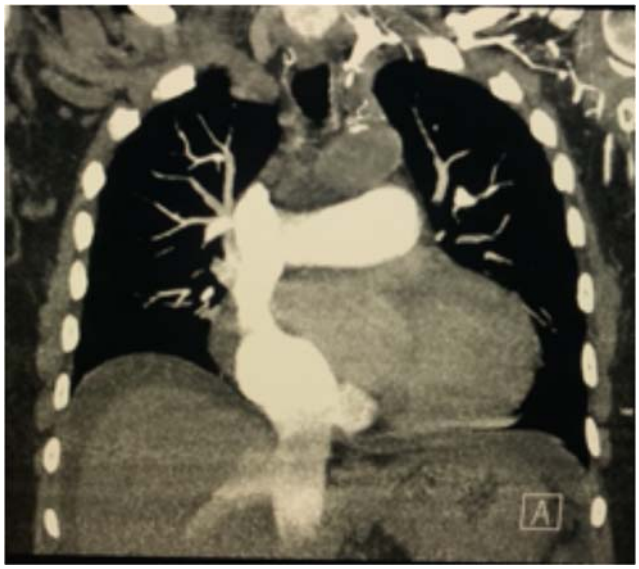

Fig. 8 Reflux of contrast

guidelines for the diagnosis of heart failure with echocardiography and included the following; impaired left ventricular systolic dysfunction, defined as an ejection fraction less than 40% and hypertensive heart disease (HHD), diagnosed as an ejection fraction above 40% with the presence of moderate or severe left ventricular hypertrophy (LVH); Valvular heart disease (VHD) was diagnosed as at least moderate: mitral valve incompetence, aortic incompetence (AI) or aortic stenosis (AS). Note that the severity of the diagnostic criteria (trivial, moderate or severe) was quantified by the cardiac technician. Aortic stenosis was graded according to the mean aortic pressure gradient (mmHg), with a value above 50 mmgHg being severe. Patients were also required to have a documented BNP from lab data of above 400 pg/ml as well as at least one of the above echocardiogram abnormalities. This was determined to be an appropriate method of identifying patients with true heart failure as per ESC guidelines and as shown in Fig. 1 [1]. Patients identified were first inserted with their names anonymised into an excel document. Data was then transferred to the SPSS software package (version 11.0; SPSS, Inc., Chicago, IL) for further data analysis. Chi square test was used to identify findings from the CTPA reports that were specific for a diagnosis of heart failure. Statistical significance was taken to be $P < 0.05$, and values that did not meet this P value were determined to be non-significant. The pre-test probability of CTPA was calculated at 1.7% given a disease prevalence of 2% [6]. Statistical significance was taken to be $P < 0.05$, and values that did not meet this P value were determined to be non-significant.

Fig. 7 Pleural effusion as seen on CTPA

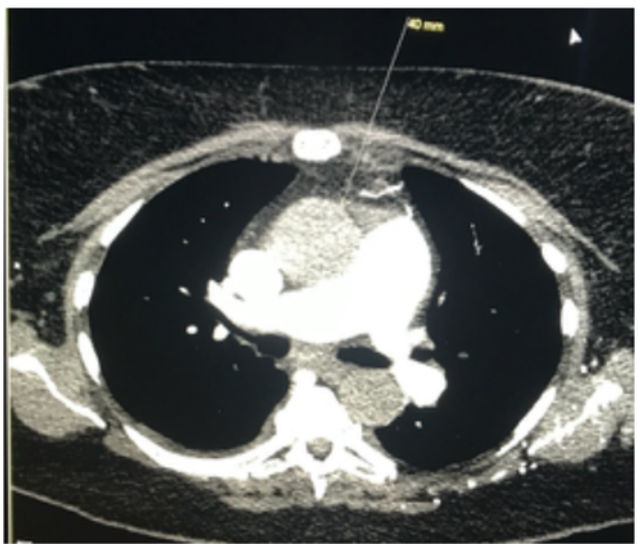

Fig. 9 Enlarged pulmonary artery and aorta

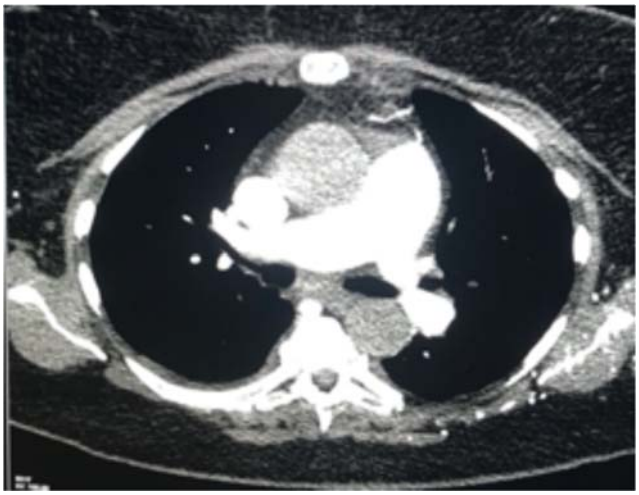

Fig. 10 Enlarged pulmonary artery

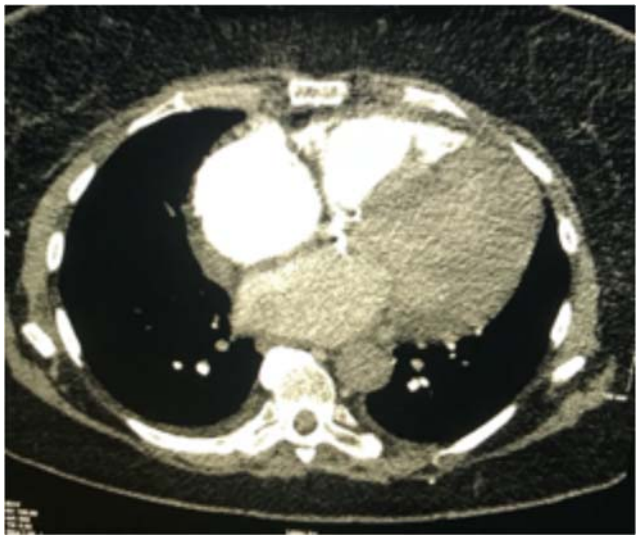

Fig. 12 Left ventricular hypertrophy

Results

In total, 230 patients were obtained for the study. Only 33 patients of these 230 had a recent echocardiogram. Of these 230 patients, only 24 (10.4%) had both objective and clinical signs of heart failure. Of the 24 patients, 15 were female and 9 were male. The average age of these patients was 74.

As per Table 1, only 24 patients were found to have had a CTPA and a recent echocardiogram with signs suggestive of heart failure, the most common being left ventricular systolic dysfunction which made up approximately half of the total patients. Other signs included diastolic dysfunction which was approximately 20% of patients.

Table 2 shows the breakdown of the CTPA findings by patient, but as per chi square analyses in Table 1. Only a small proportion of these patients were shown to have heart failure defined by having a BNP > 400 pg/ml and echocardiography signs suggestive of heart failure.

From the chi square analysis, the criteria as shown in Table 3 found on CTPA most specific for a diagnosis of heart failure were right ventricular enlargement (value = 5.426 P = 0.02), left atrial enlargement (value = 4.9 P = 0.027) and left ventricular enlargement (value = 5.692 P = 0.017). Other objective signs were not shown to reach that of clinical significance, i.e. ($P < 0.05$), the closest being right atrial enlargement and biventricular enlargement.

Again, the most specific signs of heart failure were shown to be left ventricular hypertrophy, right ventricular enlargement and left atrium enlargement.

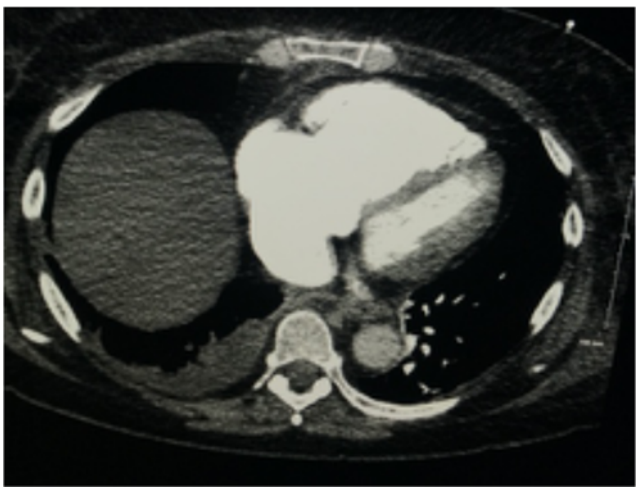

Fig. 11 Enlarged right ventricle

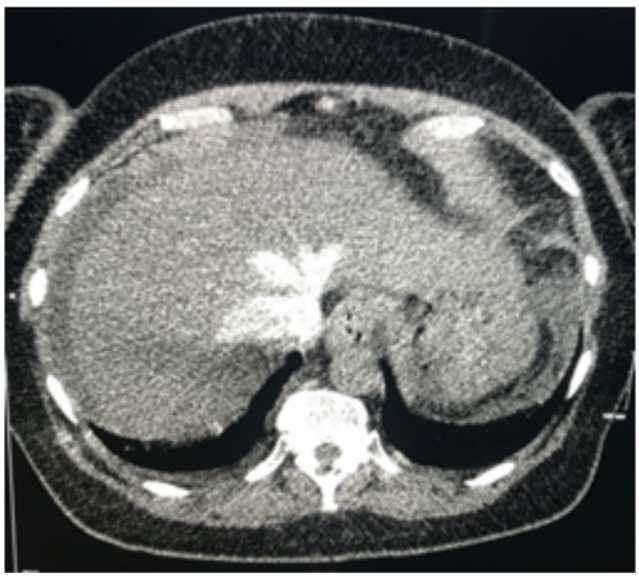

Fig. 13 Ascites and contrast reflux

Table 1 Objective signs of heart failure as per echocardiography criteria

		Number	Percentage
Left ventricular systolic dysfunction	Ejection fraction < 40%	12	50
Diastolic dysfunction	Transmitral doppler reversed	5	20.8
	Tissue doppler reversed	2	8.3
Hypertensive heart disease	Left ventricular hypertrophy	1	4.2
	Ejection fraction > 40%	1	4.2
Valvular heart disease	Mitral valve regurgitation moderate/severe	2	8.3
	Tricuspid regurgitation moderate/severe	1	4.2
Total		24	100

Discussion

Only a small proportion of patients, that is 24 of the 230 (10.4%), were shown to have heart failure in our study. This was higher than in previous studies investigating the use of CTPA for the diagnosis of heart failure. In the UK, Chandra et al. (2013) showed a prevalence of 7.6% [7]. Our study relied on strict ESC criteria, in that we required recent echocardiography and a recent BNP, and thus there are probably many patients that were excluded due to this, and the actual prevalence of heart failure is likely to be higher. Kang et al. reported the sensitivity and specificity of CT in demonstrating right heart dysfunction to be 81% and 47% respectively [8] (Table 4). Another recent study has shown that CT-derived left atrial area is a strong predictor of increased pulmonary artery wedge pressure in patients with suspected pulmonary hypertension which can again be of use for patients with signs and symptoms suggestive of HF [9]. Both Safdar et al. and Katikreddy et al. found LA area to be a predicted development of heart failure in patients with pulmonary hypertension [10, 11]. In our study, the most specific signs were shown to be left ventricular enlargement, left atrial enlargement and right ventricular enlargement. Another study demonstrated that the size of the left atrium was correlated with increased BNP values [4]; we did not correlate these values in our study, and it would be useful to include these measurements in a follow-up study. Similarly, in our follow-up study more data on the reflux of contrast, LA area, and RV to LV ratios should be collected. However, our study has shown that more simple objective measures can be used to provide useful clinical information and could be readily utilised by clinicians. It is important to mention that a high percentage of the patients in our study had left ventricular systolic dysfunction, about 52%, and thus, perhaps some 'right heart failure' signs could have been observed on CTPA if we had a greater number of these patients to meet statistical significance. A future study should probably divide

Table 2 Summary of heart failure signs observed on CTPA

CTPA Feature	No heart failure	Heart failure	Total
Cardiomegaly			
No cardiomegaly	4	14	18
Cardiomegaly	5	9	14
Total	9	23	32
Calcification of pericardium or pericardial vessels			
No calcification	6	8	14
Calcification	3	15	18
Total	9	23	32
Pleural effusion			
No pleural effusion	7	11	18
Pleural effusion	2	12	14
Total	9	23	32
Pericardial effusion			
No pericardial effusion	7	19	26
Pericardial effusion	2	4	6
Total	9	23	32
Biventricular enlargement			
No biventricular enlargement	9	17	26
Biventricular enlargement	0	6	6
Total	9	23	32
Left ventricular enlargement			
No left ventricular enlargement	9	13	22
Left ventricular enlargement	0	10	10
Total	9	23	32
Interstitial oedema			
No interstitial oedema	8	16	24
Interstitial oedema	1	7	8
Total	9	23	32
Biatrial enlargement			
No biatrial enlargement	8	18	26
Biatrial enlargement	1	5	6
Total	9	23	32
Left atrium enlargement			
No left atrium enlargement	9	14	23
Left atrium enlargement	0	9	9
Total	9	23	32
Right atrium enlargement			
No right atrium enlargement	9	17	26
Right atrium enlargement	0	6	6
Total	9	23	32
Dilated intrahepatic veins			
No dilated intrahepatic veins	7	20	27
Dilated intrahepatic veins	2	3	5
Total	9	23	32
Right ventricular enlargement			
No right ventricular enlargement	5	21	26
Right ventricular enlargement	4	2	6
Total	9	23	32

Table 3 Pearson chi square results of CTPA

CTPA Feature	Value	*P* Value
Left ventricular enlargement	5.692	0.017
Right ventricular enlargement	5.426	0.02
Left atrial enlargement	4.9	0.027
Right atrial enlargement	2.89	0.089
Biventricular enlargement	2.890	0.089
Calcification of pericardium or coronary arteries	2.672	0.102
Pleural effusion	2.358	0.125
Interstitial oedema	1.288	0.256
Cardiomegaly	0.709	0.400
Biatrial enlargement	0.480	0.489
Dilated intrahepatic vein	0.413	0.520

patients into those with right and left heart failure separately in order to improve the power of the study.

The waiting time for echocardiography is several days in our institution depending on urgency; therefore, submitting a request could potentially delay treatment and discharge of patients and contribute to the overall economic burden of heart failure. From our study, there are key features on CTPA that can be used for the early identification of heart failure including left ventricular enlargement, left atrial enlargement and right ventricular enlargement. From our study, CTPA was shown to match gold standard echocardiography closely in detecting abnormalities as per the chi square analysis; right ventricular enlargement (value = 5.426 $P = 0.02$), left atrial enlargement (value = 4.9 $P = 0.027$) and left ventricular enlargement (value = 5.692 $P = 0.017$). However, despite the usefulness shown from our results, CTPA is not a replacement for echocardiography. Indeed, echocardiography has numerous advantages; echocardiography allows for the measurement of flow Doppler crucial to assessing the integrity of valves and ejection fraction percentages [12]. Echocardiography also permits visualisation of thrombus in the right heart cavities or in some locations of the central pulmonary artery, and may provide alternative diagnoses, such as aortic dissection, pericardial disease and myocardial infarction [13]. Echocardiography is a non-contrast study and can be done at the bed-side by skilled staff. This is especially useful considering that some patients with heart failure may not be stable enough for transfer to the radiology department. Conversely, CTPA can provide some advantages over echocardiography including assessment of the pulmonary vascular bed, the consequences of pulmonary vascular bed obstruction at the heart and assessing upstream consequences at the level of abdominal and thoracic venous structures [4]. Another feature is that CTPA is less operator-dependent than echocardiography and is less susceptible to variations in body habitus. While our study suggests the benefits for physicians in utilising CTPA, it is important to consider findings by Morgan et al. who recognised that between 2009 and 2010, the use of CT has quadrupled; however, they also importantly note that this increase in radiological investigations has not significantly changed patient outcomes [14]. Excessive use of CT not only leads to a potential for over diagnosis but also exposes patients to ionising radiation and may also lead to prolonged hospital stays and significant costs [14].

Table 4 Specificity test results for CTPA for the diagnosis of heart failure

CTPA Feature	Specificity	95% CI
Cardiomegaly	44.4%	13.70 to 78.80%
Calcification of pericardium or coronary arteries	66.67%	29.93 to 92.51%
Pleural effusion	77.78%	39.99 to 97.19%
Pericardial effusion	77.78%	39.99 to 97.19%
Biventricular enlargement	100.00%	66.37 to 100.00%
Left ventricular enlargement	100.00%	66.37 to 100.00%
Interstitial oedema	88.89%	51.75 to 99.72%
Biatrial enlargement	88.89%	51.75 to 99.72%
Left atrium enlargement	100.00%	66.37 to 100.00%
Right atrium enlargement	100.00%	66.37 to 100.00%

Conclusion

This study has shown CTPA findings of left ventricular enlargement, left atrial enlargement and right ventricular enlargement, to be specific, for a diagnosis of heart failure and meeting statistical significance. However, given the limitations of CTPA in comparison with echocardiography (inability to measure ejection fraction and valvular integrity etc.) and the side-effects in terms of radiation dose, its usefulness is limited in terms of assessing the functional severity of heart failure. However, in cases where patients have already recently obtained a CTPA for the evaluation of pulmonary embolus and where there is uncertainty as to the diagnosis of heart failure clinically and/or a delay in other investigations, CTPA can provide the diagnosis. A larger prospective follow-up study would be useful to determine the usefulness of CTPA in clinical practice in terms of how it would affect patient management and treatment.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. This article does not contain any studies with human participants or animals performed by any of the authors. This study was approved by the ethical committee of University of Limerick Hospital Group.

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