Journal of Cardiovascular Computed Tomography 10 (2016) 466–472

Contents lists available at ScienceDirect

Journal of Cardiovascular Computed Tomography

journal homepage: www.JournalofCardiovascularCT.com

Research paper

Clinical and prognostic correlates of pulmonary congestion in coronary computed tomography angiography data sets

J. Tobias Kühl [a, *], Thomas S. Kristensen [b], Anna F. Thomsen [a], Louise Hindsø [a], Kristoffer L. Hansen [b], Olav W. Nielsen [c], Henning Kelbæk [d], Klaus F. Kofoed [a, b]

[a] Department of Cardiology, The Heart Centre, Rigshospitalet, University of Copenhagen, Denmark
[b] Department of Radiology, Diagnostic Centre, Rigshospitalet, University of Copenhagen, Denmark
[c] Department of Cardiology, Bispebjerg Hospital, University of Copenhagen, Denmark
[d] Department of Cardiology, Roskilde Sygehus, Roskilde, Denmark

ARTICLE INFO

Article history:
Received 26 May 2016
Received in revised form
9 September 2016
Accepted 14 September 2016
Available online 15 September 2016

Keywords:
Cardiac computed tomography
Cardiac computed tomography angiography
Heart failure
Pulmonary edema
Myocardial infarction

ABSTRACT

Background: Signs of pulmonary congestion obtained from cardiac computed tomography angiographic (coronary CTA) images have not previously been related to clinical congestion or outcome and the clinical value is, therefore, unknown. Our objective was to test the hypothesis that signs of pulmonary congestion predict clinical heart failure and adverse outcome in patients with myocardial infarction.
Methods: Coronary CTA was performed before invasive treatment in 400 prospectively included patients with non ST segment elevation myocardial infarction in an observational study. Using a previously described chest computed tomography evaluation algorithm, patients were classified as having "no congestion", "mild to moderate congestion" or "severe congestion".
Results: Using multivariate analyses, presence of pulmonary congestion on coronary CTA images was associated with age, female gender, left ventricular ejection fraction (LVEF) and left atrial size. The diagnostic accuracy for predicting clinical heart failure, defined as Killip class >1, was: sensitivity: 83%, specificity: 69%, positive predictive value: 25%, and negative predictive value: 97%. The median follow-up time was 50 months and the study end-point of death or hospitalization due to heart failure was reached in 68 (16%) patients. In a Cox proportional hazards model with adjustments for known risk factors and Killip class, the presence of "mild to moderate congestion" and "severe congestion" was independently associated with adverse outcome (Hazard ratio: 2.6 (95% CI:1.3–5.0) and 3.2 (1.3–7.5)).
Conclusion: Signs of pulmonary congestion on coronary CTA images are closely correlated to cardiac dysfunction, predict clinical heart failure, and provide prognostic value independent of LVEF and Killip class.

1. Introduction

Clinical signs of heart failure are closely associated with adverse outcome in patients with coronary artery disease and an accurate assessment of heart failure status is, therefore, important for risk stratification.[1–3] Assessment of pulmonary congestion on computed tomographic (CT) images has previously been described.[4–7] Studies assessing the relation to pathophysiological determinants and the relation to clinical heart failure status and outcome have, however, not been conducted in any patient group.

Pulmonary congestion arises primarily in the clinical setting as a consequence of left ventricular cardiac failure with either systolic or diastolic dysfunction or both. The presence of pulmonary congestion is routinely assessed by clinical examination, chest X-ray and chest ultrasound. In patients where coronary CT angiography (coronary CTA) is performed, CT images may also yield an accurate assessment. Computed tomographic signs of pulmonary congestion include ground-glass opacity, signs of interstitial transudate, and pleural effusion.[7] With the rapid implementation of coronary CTA in various clinical settings, the investigation of the validity of coronary CTA to detect pulmonary congestion is warranted. Currently, there is no known systematic assessment algorithm for the determination of the severity of pulmonary congestion.

* Corresponding author. Department of Cardiology, 2012 The Heart Centre, Rigshospitalet, University of Copenhagen, Blegdamsvej 94, 2100-Cph, Denmark.
E-mail address: Tobiaskh@gmail.com (J.T. Kühl).

http://dx.doi.org/10.1016/j.jcct.2016.09.002
1934-5925/

In the current study, we tested the hypothesis that the known CT morphological indices of pulmonary congestion can be derived from coronary CTA images and that these indices correlate with the severity of left ventricular diastolic and systolic failure and predict clinical heart failure status. Furthermore, we tested the hypothesis that the presence of CT signs of pulmonary congestion is related to adverse long-term outcome. We investigated a cohort with acute coronary syndrome with elevated troponins as this patient group is expected to include patients with a range of pulmonary congestion and as individuals presenting with possible acute coronary syndrome may become an important target group for coronary CTA[8,9] in the future.

2. Methods

2.1

Consecutive patients with non-ST segment elevation myocardial infarction[10] were referred to our department and scanned with coronary CTA prior to invasive coronary investigation as part of a prospective observational research protocol.[11,12] From standard images acquired for coronary CTA, we assessed previously described radiological signs of pulmonary congestion including ground-glass opacity, signs of interstitial transudate, and pleural effusion.[7] Patients were subsequently categorized as having ‘no congestion’, ‘mild to moderate congestion’ or ‘severe congestion’ (definitions in Table 1). These categories were then related to patient characteristics, cardiac chamber size and function, and the clinical heart failure status of the patients. Contraindication to coronary CTA included a history of chronic renal disease or plasma creatinine >125 μmol/l, cardiac arrhythmia, known allergy to iodine contrast, and hemodynamic instability. The protocol was approved by the *Committees of Biomedical Research for Region Hovedstaden* (protocol number: KF01318727) and written informed consent was obtained from all patients. Patients underwent medical and invasive treatment determined by the interventional cardiologist who was blinded to CT findings.

2.2. Patient characteristics and clinical heart failure status

Cardiac chamber size and function were assessed from CT images.[13] Reduced left ventricular ejection fraction (LVEF) was defined as LVEF <45%.[14] Clinical signs of heart failure within 5 days prior to CT were recorded by chart review and defined as Killip class ≥2.[1] Patients were categorized into four *clinical heart failure status* groups: 1) patients without clinical signs of heart failure and with preserved LVEF (*non-HF PEF*), 2) patients without clinical signs of heart failure, but with reduced LVEF (*non-HF REF*), 3) patients with clinical signs of heart failure with preserved LVEF (*HF PEF*) and 4) patients with both clinical signs of heart failure and reduced LVEF (*HF REF*).

2.3. Coronary CTA imaging

The included patients were scanned with a 64-slice CT-scanner (Toshiba Aquillion, Japan). A retrospective scan was performed using the following scanner settings: Tube voltage: 120–135 kV, tube current: 380–450 mA, detector collimation: 64 × 0.5 mm and rotation time: 350–500 ms. The average radiation dose was 19 ± 4 mSv. Depending on the expected scan time, 70–100 ml of contrast agent (Visipaque 320, GE Healthcare, UK) was infused with a rate of 5 ml/s. Images were acquired during breath hold following inspiration and bolus triggering in the descending aorta using a threshold of 180 HU.

A late diastolic image used for coronary CTA analysis with a small field of view centered on the heart was reconstructed with 0.5-mm slice thickness. An additional reconstruction with a large field of view was performed from the same phase with a slice thickness and increment of 3 mm, using a standard medium soft kernel, and included the entire lung field adjacent to the heart.

For assessment of left sided cardiac chamber function, images were reconstructed with a 2 mm slice thickness at 5% intervals of the cardiac cycle. Data sets were transferred to an external workstation (Vitrea, version 6.2, Vital, Minnesota, USA) for further analysis.

2.4. Image analysis

Evaluation was performed blinded to clinical information and outcome. Reading was performed using both full and narrow view images with a standard lung window with slight adjustments to the individual patient. Images were studied in axial, sagittal and coronal planes.

Three categories of visual signs of pulmonary congestion were assessed: Ground-glass opacity, interstitial transudate, and pleural effusion. *Ground-glass opacity* (GGO) was defined as a region of increased lung tissue attenuation often with a patchy appearance with some gravitational predominance (Fig. 1A, B and 1F.).[7,15] The relation between GGO and automated assessment of pulmonary attenuation density as well as the interobserver variability of automated assessment of pulmonary attenuation density is described elsewhere.[16] Signs of *interstitial transudate* were defined by presence of one or more of the following: interlobular septal thickening or increased peribronchovascular thickening, as described previously (Fig. 1C–E).[7,15] Lastly, *pleural effusion* was assessed in full view images (Fig. 1F). Patients were placed into *CT pulmonary congestion* groups according to the number of CT congestion findings, as presented in Table 1.

Interobserver variability was assessed by a second observer in 50 patients where half were randomly chosen from patients with preserved LVEF and half were randomly chosen from patients with reduced LVEF. The second intraobserver reading of the same 50 patients was performed after six months.

From CT images, the left atrial maximal volume and the left ventricular end-diastolic volume were indexed to body surface area and LVEF was assessed as previously described.[13]

2.5. Clinical outcome

The clinical outcome of all patients was recorded for at least 2 years. The primary end-point was a composite of death from any cause and hospitalization for heart failure. Information on mortality

Table 1
CT pulmonary congestion groups.

No congestion	Mild to moderate congestion	Severe congestion
No signs of pulmonary congestion on CT images	1 of the following CT signs of congestion found. • Ground-glass opacity. • Interstitial transudate. • Pleural effusion.	>1 of the following CT signs of congestion found. • Ground-glass opacity. • Interstitial transudate. • Pleural effusion.