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Common Incidental Findings on Cardiac CT: a Systematic Review

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Abstract

Purpose of Review Cardiac computed tomography (CT) is an established tool for evaluating cardiovascular disease, which may incidentally depict extracardiac findings (ECF). The aim of this study is to identify the spectrum and the prevalence of incidental findings detected on cardiac CT.

Recent Findings This systematic review found a median ECF occurrence of 45% in cardiac CT (range, 7–100%) among papers published between 2006 and 2018. The median clinically significant ECF occurrence was 17% (1–67%) among studies. Respectively, the five most commonly reported ECF were lung nodules or masses, lung parenchymal changes, lymphadenopathy, emphysema, and liver nodules or cysts.

Summary ECF are frequently encountered on cardiac CT. Therefore, interpreting physicians should be aware of the occurrence of clinically significant findings and be familiar with the follow-up recommendations endorsed by current guidelines.

Keywords Computed tomography · Coronary angiography · Incidental findings · Extracardiac findings · Non-coronary · Systematic review

Introduction

Cardiovascular diseases are the most common causes of death in the USA and worldwide [1, 2]. Cardiac computed tomography (CT) has emerged as a clinically useful non-invasive imaging modality that has occupied a wide gamut of roles in the management of cardiovascular diseases, including the diagnosis of coronary artery disease and pre-procedural planning for transcatheter interventions [3]. Although cardiac CT protocols are optimized for evaluating the cardiac anatomy or function, the inherent nature of image acquisition in CT inevitably encompasses other anatomic structures in the field of view, to different extents depending on operator settings. Cardiac CT was shown to include from 26% up to 86% of the lung anatomy when a standard field of view is selected (i.e., using the manufacturer's settings) [4]. As a result, cardiac CT may reveal a wide range of extracardiac findings (ECF), not only in the lungs but also in anatomic structures distant from the heart. This is particularly the case in transcatheter aortic valve implantation (TAVI) planning CT, which includes the abdominal and pelvic anatomy [5].

Though many of the ECF encountered in cardiac CT are devoid of clinical significance, one should consider the potential negative impacts of missing significant incidental findings. Major incidental ECF can be encountered in about 16% of cardiac CT, according to a meta-analysis published in 2013 [6]. Moreover, even when an incidental finding is encountered, physicians interpreting cardiac CT may also miss the opportunity of providing adequate follow-up recommendations. A retrospective single-center study showed that only a third of significant findings were adequately addressed by follow-up recommendations on cardiac CT reports [7]. Therefore, it is crucial that interpreting physicians be familiar with common ECF and their management recommendations.

The objective of this paper is to systematically review the literature to determine the most common incidental findings expected to be found on cardiac CT. We will also provide further references to current imaging guidelines for management

This article is part of the Topical Collection on *Cardiac Computed Tomography*

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or follow-up of the most common ECF. This paper is written from the standpoint of radiologists and cardiologists interpreting cardiac CT; therefore, the scope of this review is centered on the imaging method rather on the epidemiological aspects of the subpopulations studied.

Methods

This invited review article followed the PRISMA guidelines [8] and does not have a registered a priori protocol. The authors have no relevant conflict of interests to disclose.

Eligibility Criteria

We examined original research articles reporting the prevalence of extra-cardiac findings in ECG-gated cardiac CT, published in English, print or electronic. Studies including coronary CT angiography (CTA), coronary calcium score CT, pre-TAVI planning CTA, and pre-pulmonary vein isolation (PVI) planning CTA were eligible. The search was performed using the webtools of PubMed (U.S. National Library of Medicine, Bethesda, MD, USA) and Web of Science (Clarivate Analytics, Philadelphia, PA, USA), with last search dated November 6, 2018. We used the search terms provided in Table 1.

Study Selection

The search resulted in 2933 and 3324 articles on PubMed and Web of Science, respectively. One of the authors (A.C.) reviewed the title, authorship, and publication data of all 6257 articles. A total of 3260 articles were duplicated.

Table 1 Terms and logic used in the search for articles. The bottom row shows the resultant number of records using each one of the webtools (PubMed: https://www.ncbi.nlm.nih.gov/pubmed/; Web of Science: https://clarivate.com/products/web-of-science/)

PubMed	Web of Science
"incidental findings" [MeSH Terms]	TS = (incidental findings
OR accidental findings [Text Word]	OR accidental findings
OR collateral findings [Text Word]	OR collateral findings
OR incidental [Text Word]	OR incidental
OR incidental abnormalities [Text Word]	OR incidental abnormalities
OR non-cardiac [Text Word]	OR non-cardiac
OR noncardiac [Text Word]	OR noncardiac
OR extra-cardiac [Text Word]	OR extra-cardiac
OR extracardiac [Text Word]	OR extracardiac
OR noncoronary [Text Word]	OR non-coronary
OR non-coronary [All Fields]	OR noncoronary
OR extra-coronary [Text Word]	OR extra-coronary
OR extracoronary [Text Word]	OR extracoronary)
AND	AND
computed tomography [Text Word]	TS = (computed tomography)
Total: 2933	Total: 3324

The abstracts of the remaining 2997 articles were reviewed. Two additional records were included for screening after "snowballing" the reference lists of eligible articles, resulting in a total of 2999 articles screened.

After screening, articles assessing non-cardiac CT or without focus on ECF, literature review articles or meta-analyses, comments, pictorial essays, and meeting abstracts were excluded. A total of 60 articles were selected for full-text eligibility check, after which 11 were excluded: three studies based on non-ECG-gated CT, seven studies with insufficient data, and one study focusing on the pediatric subpopulation. The final cohort included 49 full-text eligible articles. The flowchart of this systematic review is illustrated on Fig. 1.

Data Collections Process

Two authors (A.C and F.K.) independently reviewed the 49 full-text articles and stored the collected data collected in an Excel workbook (Microsoft® Excel for Mac Version 16.21.1, Redmond, WA, USA). Studies are identified by the authorship and publication year. We collected data about the study design (prospective versus retrospective), number of centers involved (single versus multicenter), scanner type (if studies used 64-slice or greater multidetector CT), indication for cardiac CT, number of patients enrolled, measure of central tendency and dispersion for age, gender proportion, field-of-view (FOV) size, use of intravenous (IV) contrast media, and method of analysis (radiologic report review or post hoc image analysis). We also targeted the number of patients with at least one ECF divided by all imaged patients (expressed in percentage). Due to the heterogeneous methodology used to report the prevalence of specific classes of ECF across different articles (i.e., some studies used a per patient denominator, while others used per finding denominator), we devised a ranking approach to determine the most common ECF. For each article, we ranked the five most common ECF according to their relative frequency per study methodology. Results from different study subpopulations or methods of analysis were separately tabulated in three studies [9–11]. To facilitate interpretability, ECF were bundled into major classes determined by the reviewers (e.g., lung nodules were bundled with lung masses for the purposes of this review). FOV were also divided into two classes, named "small," when focused on the heart, and "large," when broadened to include the most of thoracic anatomy.

Summary Measures

We calculated the relative frequency of categorical variables. The median and range of the continuous variables were also determined across studies.

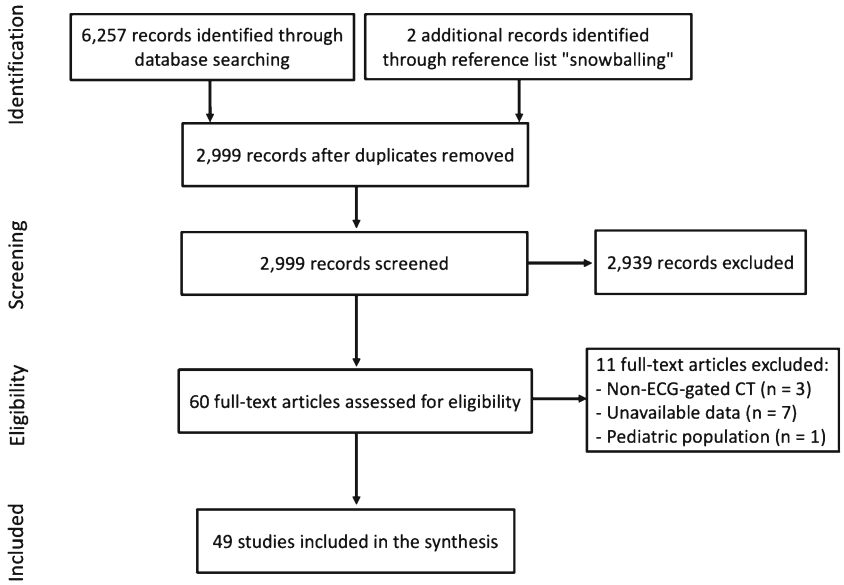

Fig. 1 Study flowchart. Flowchart summarizing the number of records at each one of the steps: identification, screening, eligibility check, and inclusion

Synthesis of Results

To synthesize the most common classes of ECF, we developed a scoring system using the top five ECF extracted from each study. For this scoring system, the class listed as the most common ECF in a study subpopulation received five arbitrary points, the second class received four points, the third class received three points, the Fourth class received two points, and the fifth class received one point. The final score for each ECF class was computed as the sum of all arbitrary points. This arbitrary score was used for final ECF ranking.

Results

All of the 49 selected studies were published between the years 2006 and 2018. The study design was prospective in 15 studies (31%), retrospective in 32 studies (65%), and unclear in two studies (4%). Forty-three articles reported the results of single-center studies (88%), while six articles reported the results of multicenter studies (12%). Multidetector CT scanners acquiring 64 simultaneous slices or more were employed in 34 studies (69%). Assessment of coronary artery disease was the indication in 29 studies (59%), pre-TAVI workup was the indication in 12 studies (25%), pre-PVI workup was the indication in five studies (10%), coronary artery bypass graft evaluation was the indication in two studies (4%), and various indications were included in one study (2%). A total of 41,543 patients were imaged across all studies. The median estimate of central tendency for age was 60 years (range 42–82). The median proportion of female subjects was 41% (range 0–65%). A large FOV was available for review in 32 studies (64%); a focused cardiac FOV was available in 11 studies (22%); one study (2%) compared the effect of large and focused FOV in two subpopulations; the FOV information was missing in five studies (10%). Thirty-seven studies (76%) were obtained with IV contrast, four studies (18%) without IV contrast, and eight (16%) without and with contrast. Table 2 details the data.

The method for assessing the ECF prevalence was radiologic report review in 24 studies of the 49 studies (49%) and post hoc image review in 25 studies (51%). The overall median prevalence of any ECF (range within parentheses) was 45% (7–100%), while the median prevalence of only potentially clinically significant ECF was 17% (1–67%). Considering the primary indication for the cardiac CT, the prevalence of all ECF was 42% (7–80%) for coronary artery disease evaluation, 44% (13–76%) for coronary artery bypass graft evaluation, 70% (25–100%) for pre-TAVI evaluation, and 69% (23–80%) for pre-PVI evaluation. Prevalence of ECF in studies making use of large FOV was 46% (8–100%) versus 43% (7–79%) in studies with small FOV. The prevalence of ECF in studies with and without IV contrast was 43% (8–100%) and 41% (8–56%), respectively. Across all studies, lung nodules and masses were the most common findings, followed by lung parenchymal changes (excepting emphysema), lymphadenopathy, emphysema, liver cysts or nodules, aortic dilation or aneurysm, pleural effusions or plaques, and hiatal hernia. All of the ECF classes with their respective rank scores are shown in Fig. 2.

Discussion

Allowing for the clinical and methodological heterogeneity encountered among studies addressing ECF in the cardiac CT literature, overall, physicians interpreting those studies should expect to encounter at least one ECF in

Table 2 Characteristics of the 49 studies. Law et al. studied subpopulations of patients undergoing coronary calcium scoring (a) and coronary CTA (b). Aglan et al. studied subpopulations under two protocols including large (a) and small (b) FOV reconstructions. Reinschmidt et al. studied HIV-positive (a) and negative (b) subpopulations. #—Central tendency, mean if not specified otherwise. *—Median. $—Age dispersion reflects standard deviation if not specified otherwise. [], interquartile range. {}, range. $^{\alpha}$—Percentage per all ECF, therefore excluded from synthesis. FOV, field-of-view; WO, without IV contrast; W, with IV contrast; ECF, extracardiac findings, per patient prevalence; CAD, coronary artery disease (includes calcium scoring or coronary CTA); PVI, pulmonary vein isolation; CABG, coronary artery bypass graft; TAVI, transcatheter aortic valve implantation; NA, not available

Authorship	Year	Design	Indication	Patients (*n*)	Age#	Age dispersion$	Female (%)	FOV	Contrast	ECF (%)	Significant ECF (%)
Onuma et al. [12]	2006	Retrospective	CAD	503	66	9.9	24%	S	W	58.10	22.67
Haller et al. [13]	2006	Prospective	CAD	166	64	NA	26%	NA	W	24.70	4.80
Law et al. [9](a)	2007	Retrospective	CAD	140	56	NA	44%	L	WO	NA	8.00
Law et al. [9](b)	2007	Retrospective	CAD	295	56	NA	33%	L	W	NA	19.00
Schietinger et al. [14]	2007	Retrospective	PVI	149	56	11	25%	L	W	69.00	NA
Kirsch et al. [15]	2007	Retrospective	CAD	100	63	14.5	32%	L	W	67.00	11.00
Cademartiri et al. [16]	2007	Retrospective	CAD	670	60	10.2	43%	S	W	79.40	12.08
Mueller et al. [17]	2007	Retrospective	CABG	259	64	{37–89}	27%	S	W	13.10	NA
Kawano et al. [18]	2007	Prospective	CAD	617	66	12	44%	S	W	24.15	5.80
Dewey et al. [19]	2007	Prospective	CAD	108	63	9	26%	L	W	15.00	5.00
Gil et al. [20]	2007	Prospective	CAD	258	54	7.9	22%	L	W	56.20	NA
Greenberg-Wolff et al. [21]	2008	Prospective	CAD	134	54	{20–77}	22%	L	WO/W	76.80	39.00
Koonce et al. [22]	2008	Retrospective	CAD, PVI, CABG	1764	58	{18–91}	39%	L	WO/W	25.43	18.40
Wissner et al. [23]	2008	Retrospective	PVI	95	62	10	35%	S	WO	51.00	NA
Burt et al. [24]	2008	Prospective	CAD	459	66	2.8	52%	L	WO	41.00	23.00
MacHaalany et al. [25]	2009	Prospective	CAD	966	58	16	45%	L	W	41.50	1.20
Lehman et al. [26]	2009	Prospective	CAD	395	53	12	37%	L	W	44.80	20.50
Chia et al. [27]	2009	Retrospective	CAD	1061	56	{35–77}	35%	L	W	8.00	3.10
Kim et al. [28]	2009	Retrospective	CAD	254	59	13.1	44%	S	WO/W	7.00	1.57
Turkvatan et al. [29]	2009	Retrospective	CAD	375	56	{20–88}	37%	L	W	41.30	19.20
Bendix et al. [30]	2010	Retrospective	CAD	1383	56	11	54%	L	W	28.00	6.80
Johnson et al. [31]	2010	Retrospective	CAD	6920	55	11.9	35%	L	W	23.70	16.20
Lee et al. [7]	2010	Retrospective	CAD	151	54*	{18–83}	31%	L	W	43.00	31.00
Lazoura et al. [32]	2010	Retrospective	CAD	1044	61	NA	26%	L	W	56.00	15.00
Aglan et al. [10](a)	2010	NA	CAD	542	58	11.2	45%	L	W	43.20	24.40
Aglan et al. [10](b)	2010	NA	CAD	542	58	10.2	43%	S	W	33.60	14.40
Martins et al. [33]	2011	Retrospective	PVI	250	55	9.6	18%	S	WO	23.20	NA
Crum-Cianflone et al. [34]	2011	Retrospective	CAD	215	43*	[36–50]	0%	S	WO/W	43.00	17.00
Sohns et al. [35]	2011	Prospective	PVI	158	61*	{21–100}	32%	L	W	72.00	43.00
Apfaltrer et al. [36]	2012	Retrospective	TAVI	207	81	5.7	65%	L	W	48.80	18.40
Cho et al. [37]	2013	NA	CAD	620	66	8.7	51%	S	W	17.70	NA
Orme et al. [38]	2014	Retrospective	TAVI	424	82*	8.3	38%	L	W	98.60	67.20
Staab et al. [39]	2014	Prospective	TAVI	204	81	5.1	48%	NA	W	70.60	17.10
Jaar et al. [40]	2014	Prospective	CAD	260	55	13.5	42%	S	WO	55.80	NA
Espinoza et al. [41].	2014	Prospective	CAD	571	55	8	62%	L	W	48.00	NA
Sohns et al. [42]	2014	Retrospective	PVI	224	64	10	37%	L	W	80.00	31.70$^{\alpha}$
Gufler et al. [43]	2014	Retrospective	TAVI	131	82	NA	47%	L	W	100.00	23.70
Lindsay et al. [44]	2015	Retrospective	TAVI	188	79	8.9	45%	L	W	54.80	19.30
La Grutta et al. [45]	2015	Retrospective	CAD	4303	60	10.2	37%	L	W	79.89	4.40$^{\alpha}$
Roller et al. [46]	2015	Retrospective	TAVI	76	82	5.4	61%	L	WO/W	NA	1.40
Hussien et al. [47]	2016	Retrospective	TAVI	209	70	{59–94}	46%	L	WO/W	85.60	37.80
Lu et al. [48]	2017	Prospective	CAD	4633	61	8.2	52%	L	W	11.60	NA
Fathala et al. [49]	2017	Retrospective	TAVI	67	73	8	48%	L	W	100.00	4.50
Markowiak et al. [50]	2018	Retrospective	TAVI	976	79	[72–86]	52%	L	W	36.99	NA
Karius et al. [51]	2018	Retrospective	CAD	3898	59	12.4	51%	NA	W	30.20	2.90
Patel et al. [52]	2018	Retrospective	TAVI	138	80	7.3	46%	L	W	69.57	17.00
Feyz et al. [53]	2018	Retrospective	TAVI	916	78	10 $	46%	NA	W	43.12	7.50
Reinschmidt et al. [11](a)	2018	Retrospective	CAD	341	42	[49–57]	12%	S	W	48.00	9.00
Reinschmidt et al. [11](b)	2018	Retrospective	CAD	212	56	[51–62]	23%	S	W	60.00	10.00
Trenkwalder et al. [54]	2018	Retrospective	TAVI	1050	80	7 $	47%	L	W	24.57	25.00
Boldeanu et al. [55]	2018	Prospective	CABG	144	69	[64–75]	15%	L	WO/W	75.69	25.00
Williams et al. [56]	2018	Prospective	CAD	1778	59	9 $	45%	NA	W	38.00	10.00

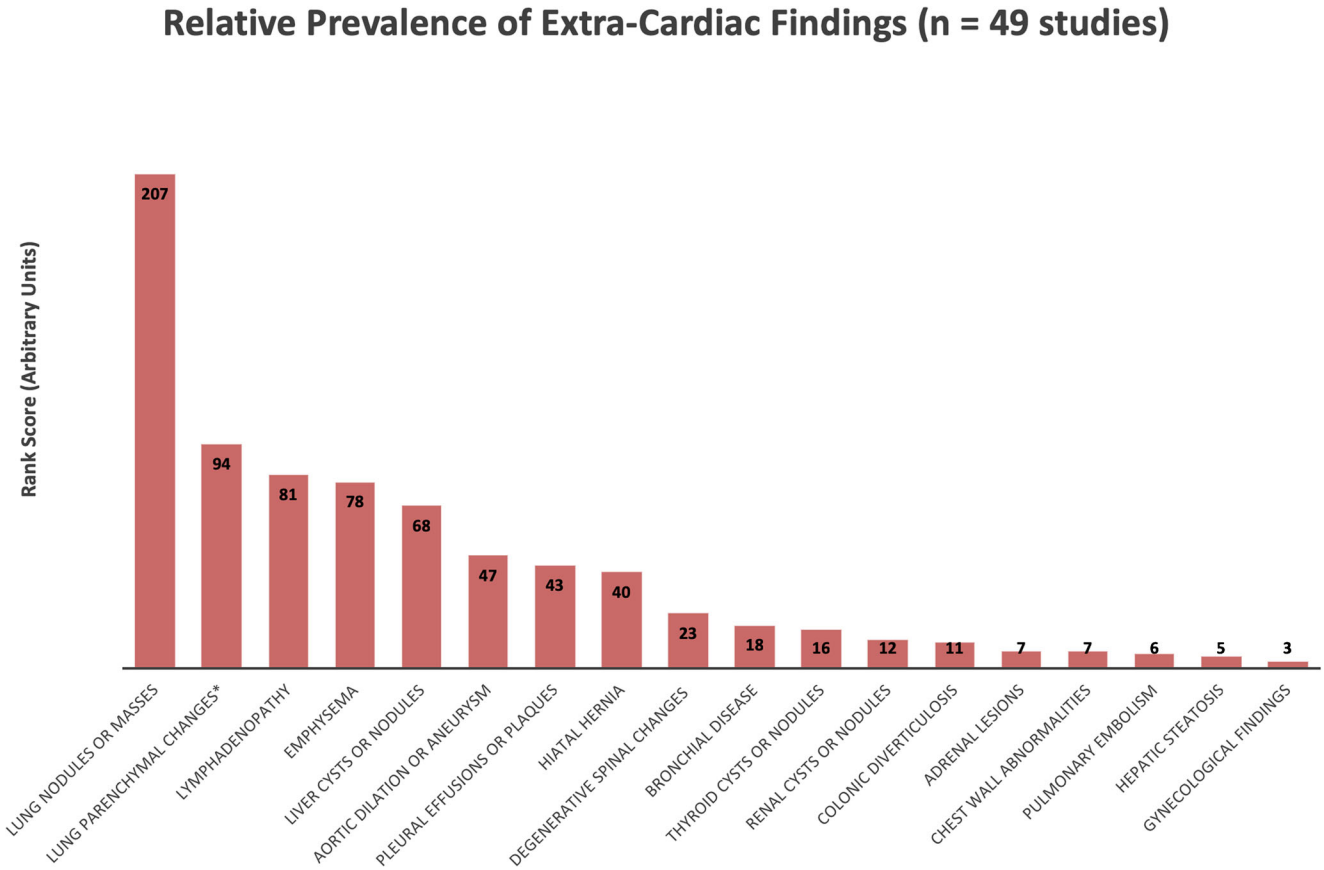

Fig. 2 Bar chart. Rank score (in arbitrary units) of the most common incidental extracardiac findings across 49 studies. Excepting emphysema (asterisk)

about 45% patients. In a meta-analysis published in 2014, Karius et al. found a similar ECF prevalence of 41% in cardiac CT [57].

In the study with the lower ECF prevalence in our systematic review, Kim et al. found at least one ECF in 7% of the patients undergoing cardiac CT [28]. These findings were based on independent review of images with FOV focused on the cardiac anatomy by two radiologists. The patients from this study also underwent a full-chest FOV low-dose CT (LDCT) prior to the acquisition of the cardiac CT, which yielded a higher ECF prevalence of 62.6% [28]. In another study, Chia et al. retrospectively reviewed the images and reports of 1061 patients undergoing cardiac CT in a single center. A radiologist specifically reviewed the large FOV for the presence of ECF, which were found in 8% of the sample. Significant ECF (i.e., those requiring radiologic or clinical follow-up) represented approximately 50% of all ECF in this study [27].

At the other end of the spectrum, two papers reported an ECF prevalence of 100% in patients undergoing cardiac CT [43, 49]. Both articles studied cardiac CT performed in anticipation for TAVI. In Gufler et al. [43], a radiologist retrospectively reviewed the thoracic and abdominal components of a pre-TAVI cardiac CT of 131 patients with a typical FOV of 32 cm. Though ECF were found in all patients, significant findings were only present in 23.5% of the whole sample. In addition, confirmed or suspected malignancy only occurred in 3.8% of the patients [43].

Differences in anatomical scopes between cardiac CT protocols could be one of the factors responsible for the contrasting ECF prevalence observed among studies. For instance, pre-TAVI cardiovascular CT encompasses the thoracic, abdominal, and pelvic segments, resulting in a wide gamut of anatomic structures in comparison with standard cardiac CT [5]. In addition, use of small focused cardiac FOV versus large FOV could also play a role. Aglan et al. compared two matched groups of 542 patients each undergoing coronary CTA; in one of the groups, a focused cardiac FOV was the only reconstruction available for review, while an additional large FOV (> 32 cm) was also available in the other group. They encountered a statistically significant difference in ECF prevalence of 33.6% versus 43.2% in the only focused FOV versus both small and large FOV protocols, respectively. Significant ECF were also more frequently encountered in the group with both small and large FOV when compared with the focused approach (24.4% versus 14.4%, respectively) [10]. In another study, Johnson et al. found that the focused approach would have missed 90.9% of the findings necessitating therapy and 64.1% of findings requiring workup when compared with the large FOV approach [31]. Despite these

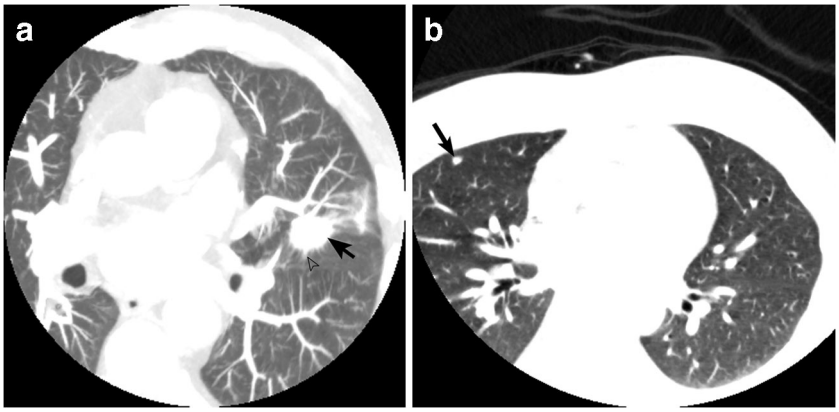

Fig. 3 **a** Axial maximum intensity projection image from coronary CT angiography showing an incidental solid nodule (arrow) with spiculated contours (open arrowhead) in the left lung, proven to be a primary adenocarcinoma. **b** Axial image from coronary calcium score study showing a solid non-calcified nodule with circumscribed contours measuring less than 6 mm in the right middle lobe, adjacent to the pleural surface. According to Fleischner Society guidelines, this finding does not require follow-up in patients without risk factors for lung cancer

results, the recommendation for routine additional large FOV reconstruction is still debatable due to lack of unequivocal evidence for its cost-effectiveness [58, 59].

One could hypothesize that specific characteristics of the subpopulations would also play a role in the ECF prevalence heterogeneity. Reinschmidt et al. compared the prevalence of ECF in subpopulations with and without HIV infection undergoing coronary CTA; the prevalence of ECF in HIV-infected patients was actually numerically lower than in non-infected patients (48% versus 60%, respectively). However, age and tobacco smoking were positively associated with the frequency of ECF [11]. In a study by Crim-Cianflone et al., the prevalence of ECF among HIV-infected men undergoing CAC scans was 43%; older age, a positive CAC score, and current tobacco smoking were also variables positively associated with the frequency of ECF in this subpopulation [34]. Jaar et al. studied ECF in a subpopulation of 260 patients with end-stage renal disease undergoing cardiac CT; the prevalence of ECF was 55.8%; and age was a significant predictor for any of the ECF [40]. Therefore, differences in age group and tobacco smoking prevalence seem to be important factors affecting the expected ECF prevalence.

Lung nodules and masses ranked as the top ECF among the studies included in this review, with a per patient prevalence of up to 38% [14]. The differential diagnosis of pulmonary nodules is broad and includes both benign and malignant causes [60] (Fig. 3). Despite continued advancement of Medicine, lung cancer continues to lead oncologic death worldwide [61]. However, early diagnosis appears to be key in reducing lung cancer mortality, as shown by results of low-dose CT screening [62]. In order to maximize detection of significant nodules, while reducing the number of false positive cases, the Fleischner Society has published recommendations for assessment and management of incidental pulmonary nodules in patients 35 or older without history of malignancy or immunosuppression [63••]. Characteristics such as size, location, shape, and density are important in determining the likelihood of cancer and should be routinely described in the radiologic report; follow-up and workup recommendations should be based on these guidelines when appropriate.

Lung parenchymal changes, such as atelectasis, consolidation, and interstitial lung disease were the second most common class of ECF encounter among studies. Recognizing these abnormalities and knowing the differential diagnosis is important to determine the need for further workup or treatment. The Fleischner Society recommends the use of

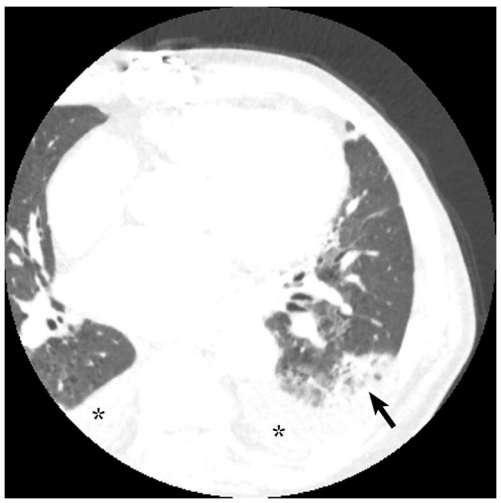

Fig. 4 Axial imaged from cardiac CT showing an incidental peripherally located focus of consolidation in the left lower lobe (arrow) and small bilateral pleural effusions (asterisks). The asymmetric distribution is atypical for pulmonary edema. Correlation with clinical presentation (e.g., fever, respiratory symptoms, elevated white cell count) may suggest the diagnosis of pneumonia. Close inspection of the pulmonary arteries should ensue to rule out pulmonary embolism (PE). Dedicated pulmonary CT angiography can be obtained depending on the lack of adequate pulmonary artery opacification and the degree of suspicion for PE

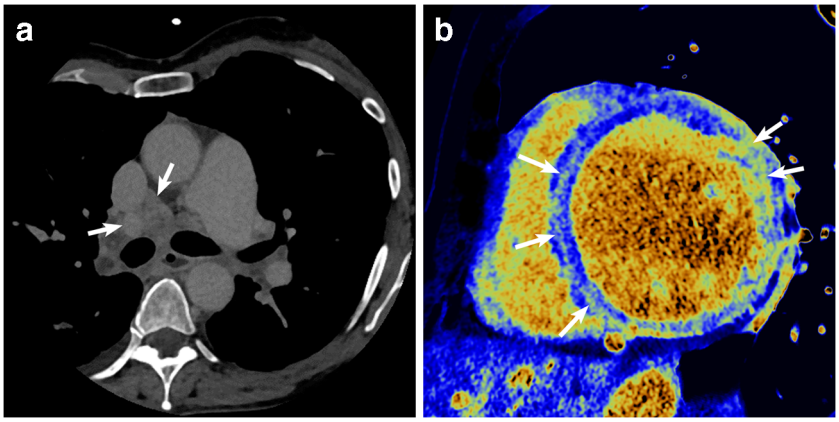

Fig. 5 **a** Axial delayed post contrast spectral cardiac CT of a patient with sarcoidosis. Note enlarged lymph nodes (i.e., measuring more than 10 mm in the short axis) in stations 4R and 10R (arrows) **b** Iodine colored mapping short axis reconstruction through the basal left ventricle obtained 10 min after contrast injection. Hot colors represent higher concentration of iodine. Note areas of linear and patchy mid-wall (mesocardial) enhancement in the septum and anterolateral wall of the left ventricular (arrows) which can be seen in cardiac sarcoidosis

standardized terms for describing lung abnormalities in order to increased precision and facilitate communication. The illustrated glossary of terms for thoracic imaging can be found elsewhere [64]. For instance, the discovery of an incidental consolidation (Fig. 4) should prompt the radiologist to think about pneumonia, infarct, alveolar hemorrhage, edema, or tumor as differential diagnoses. Correlation with clinical presentation is key for narrowing the possibilities.

Enlarged lymph nodes were the third most common class of ECF in the review. Lymphadenopathy is historically defined as an increase in the short axis diameter of a mediastinal lymph node to more than 10 mm [65]. Congestive heart failure (CHF) is regarded as one of the frequent causes for lymphadenopathy in patients undergoing cardiac and chest CT. The key diagnostic element for this benign cause of lymph node enlargement is the regression with CHF treatment [66, 67]. Differential diagnoses for lymphadenopathy also include malignancies (nodal metastasis and lymphoma), sarcoidosis (Fig. 5), and inflammatory lymph nodes secondary to interstitial lung disease [68–70].

Emphysema was the fourth most common class of ECF (Fig. 6). As in other manifestations of chronic obstructive pulmonary disease (COPD), emphysema results from structural damage to the lungs caused by tobacco smoking [71]. The Fleischner Society has provided recommendations for defining and quantifying different emphysema phenotypes to improve diagnostic accuracy and optimize patient management [72•]. Not only did studies show that emphysema quantification is related to decline in pulmonary functions tests [73], but also that even visual detection of emphysema is an independent risk marker for the occurrence of lung cancer [74].

Liver lesions were the fifth most common class of ECF. Incidental liver lesions have been frequently reported in the literature, with prevalence as high as 30% in patients older than 40 years [75]. The vast majority of these incidental lesions are benign, usually representing cysts (Fig. 7) or hemangiomas. The highest per patient prevalence of benign liver cysts in our review was 6.6% [26]. The American College of Radiology has proposed recommendations to address incidental hepatic lesions found on CT [75•]. The algorithm is a decision tree that takes into account the lesion size, imaging features, and patient risk, which are variables to be specifically obtained at the time of the interpretation.

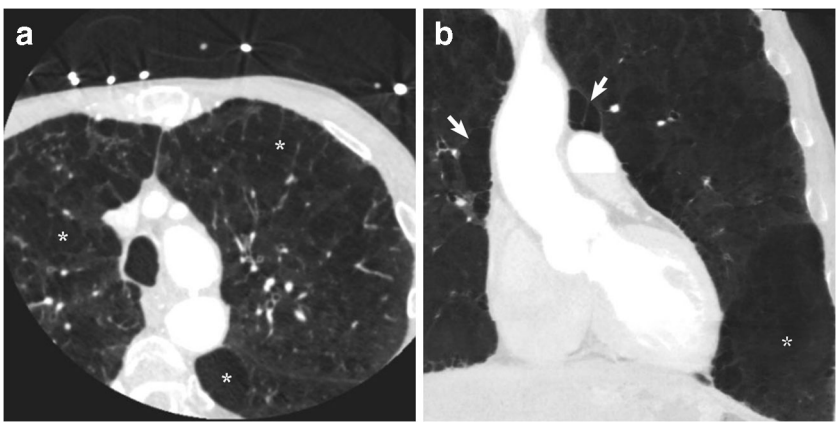

Fig. 6 **a** Axial image from cardiac CT to assess coronary artery bypass graft patency showing mottled areas of reduced lung attenuation (asterisks), consistent severe confluent centrilobular emphysema. **b** Coronal reconstruction of the same study on minimal intensity projection also reveals paraseptal emphysema (arrows) in addition to centrilobular emphysema (asterisk)

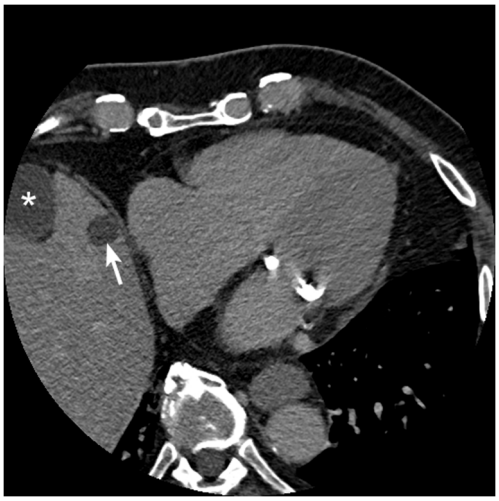

Fig. 7 Axial delayed post contrast cardiac CT to assess for intracardiac thrombus showing an incidental non-enhancing hypoattenuating hepatic lesion (arrow), consistent with a cyst. Note that the attenuation of the cyst is similar to the gallbladder (asterisk). No additional follow-up is required given the benign appearance

The sixth, seventh, and eight most common ECF classes were respectively aortic dilation or aneurysm, pleural effusion/plaques, and hiatal hernia. Guidelines on the diagnosis and management of patients with thoracic aortic disease have been published by American [76] and European Societies [77]; both guidelines recommend measurements of the aortic diameter at standardized anatomic landmarks, perpendicular to the axis of blood flow using multiplanar reformat tools (Fig. 8).

Pleural effusions of transudative nature are commonly seen in patients with congestive heart failure, with observed per patient prevalence of up to 20% in the pre-TAVI planning studies reviewed [38, 47, 50] (Fig. 9). Findings that should raise suspicion for exudative pleural effusions include presence of loculation, pleural thickening, pleural nodules, and stranding of the extrapleural fat. In addition, nodular pleural thickening or presence of pleural nodules should prompt the investigation for malignant pleura [78].

Hiatal hernias are characterized by the presence of abdominal contents protruding through an enlarged esophageal hiatus due to weakening and stretching of the phrenicoesophageal membrane. They are usually subdivided into four categories: type 1, sliding hiatal hernia (most common, 95% of cases); type 2, paraesophageal or rolling hiatal hernia; type 3, compound or mixed; and type 4, compound with additional herniation of abdominal viscera [79]. Images from upper gastrointestinal barium series are still used to confirm the finding when a surgical intervention is planned (Fig. 10).

Some studies in this review have addressed the economic impact of incidental ECF findings on cardiac CT. MacHaalany et al. [25] reviewed the medical records of 966 patients undergoing cardiac CT at a Canadian tertiary medical center, and despite the overall ECF prevalence of 41.5%, only 1.2% of all patients had clinically significant findings. Moreover, of the

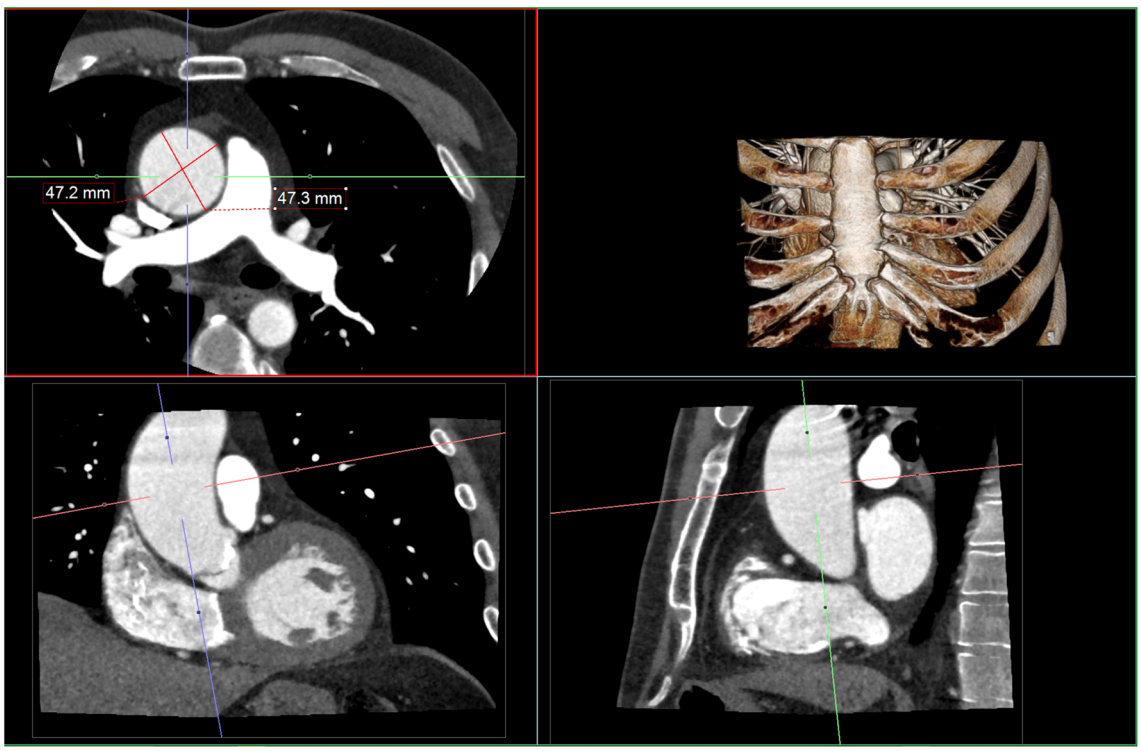

Fig. 8 Multiplanar reformation of a cardiac CT. Measurements of the dilated tubular ascending aorta should be obtained perpendicular to the axis of blood flow

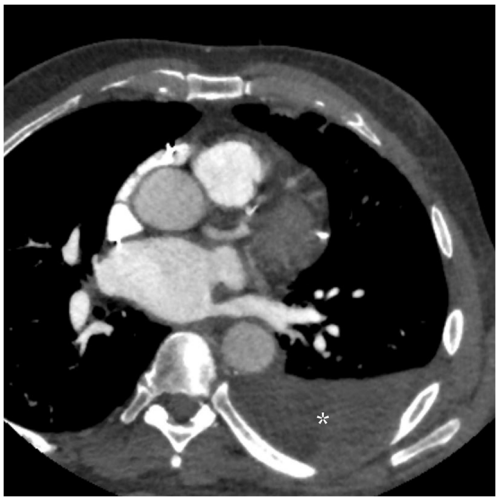

Fig. 9 Axial image of cardiac CT obtained for transcatheter aortic valve implantation planning showing a moderate incidental left pleural effusion

indeterminate ECF found in 7% of the patient sample, all were proven to be clinically insignificant and one patient suffered a major complication during workup. On the other hand, the total direct monetary costs associated with ECF workup in this study were estimated in 83,035 USD, which included the medical costs secondary to the procedural complication. Lee et al. evaluated the direct medical costs involved in the work-up of clinically significant ECF found on cardiac CT at a US tertiary academic medical center over a 7-year period, finding additional costs of 17.42 USD and 438.39 USD per all patients or only those requiring additional investigation, respectively [7]. The clinical outcomes of such follow up strategies were addressed in other studies. For instance, Lindsay et al. [44] found an average additional cost of 48.43 USD to investigate ECF encountered on pre-TAVI CT angiography in a UK tertiary medical center. Although the cost was relatively low, no significant impact on 3-year survival was observed per multivariate analysis. Goehler et al. [59] modeled the cost-effectiveness of following up incidental pulmonary nodules in a theoretical population with demographical and clinical characteristics matched to those found in stable symptomatic patients referred for coronary CT angiography, according to an outdated iteration of the Fleischner Society guidelines [80]. The authors projected a cost of 154,700 USD per quality-adjusted life-year to follow up the entire cohort of patients and of 129,800 USD to follow up only smokers.

On the other perspective of this debate, one should consider that addressing ECF on cardiac CT could explain the presentation of symptomatic patients. Karius et al. have shown that up to 7.9% or patients with significant coronary artery disease could have their symptoms potentially explained by ECF [57]. Moreover, proven or potential malignancies could be missed by simply ignoring ECF in a cardiac CT. Although pooled estimates of cancer prevalence among ECF may be as low as 0.7% [6], individual studies in older populations can yield a prevalence of potentially malignant ECF of up to 3.8% [43].

We would like to address some limitations of our study. First, we encountered a large heterogeneity on the methods used throughout the studies included in this review. In order to overcome this heterogeneity, we devised a ranking method to synthesize the most common ECF expected to be encountered on cardiac CT. Second, we only briefly discussed the most commonly reported ECF categories, providing further reading references for current recommendations on reporting and follow-up. This article is not able to cover every possible ECF expected to be encountered in clinical practice. In addition, as Medicine is an iterative science, the readers are advised to always check for the current validity and newer versions of the references provided.

Conclusions

Although ECF are commonly encountered on cardiac CT, only a minority of them will be become clinically significant. There is an ongoing debate about the cost-effectiveness and most appropriate strategies to tackle ECF. It is crucial that interpreting physicians become familiar and up-to-date with

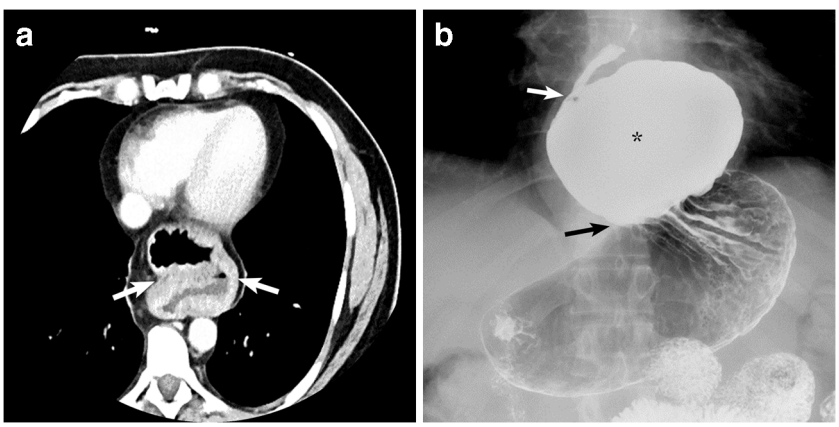

Fig. 10 a) Axial image of cardiac CT showing a large compound (type 3) gastric hiatal hernia (arrows). b) Confirmatory pre-surgical upper gastrointestinal barium series showing herniation of the gastric fundus (asterisk) and gastroesophageal junction (white arrow) through a widened hiatus (black arrow)

current reporting and follow-up recommendations endorsed by radiologic and cardiologic societies.

Compliance with Ethical Standards

Conflict of Interest All authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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