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CARDIAC

Indications, imaging technique, and reading of cardiac computed tomography: survey of clinical practice

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Abstract
Objectives To obtain an overview of the current clinical practice of cardiac computed tomography (CT).
Methods A 32-item questionnaire was mailed to a total of 750 providers of cardiac CT in 57 countries.
Results A total of 169 questionnaires from 38 countries were available for analysis (23%). Most CT systems used (94%, 207/221) were of the latest generation (64-row or dual-source CT). The most common indications for cardiac CT was exclusion of coronary artery disease (97%, 164/169). Most centres used beta blockade (91%, 151/166) and sublingual nitroglycerine (80%, 134/168). A median slice thickness of 0.625 mm with a 0.5-mm increment and an 18-cm reconstruction field of view was used. Interpretation was most often done using source images in orthogonal planes (92%, 155/169). Ninety percent of sites routinely evaluate extracardiac structures on a large (70%) or cardiac field of view (20%). Radiology sites were significantly more interested in jointly performing cardiac CT together with cardiology than cardiologists. The mean examination time was 18.6±8.4 min, and reading took on average 28.7±17.8 min.
Conclusions Cardiac CT has rapidly become established in clinical practice, and there is emerging consensus regarding indications, conduct of the acquisition, and reading.
Key Points
• *Cardiac CT has now become a routine clinical procedure*
• *Over 90% of cardiac CTs performed use at least 64 row or dual-source CT.*
• *Radiologists are significantly more interested in performing cardiac CT together with cardiologists than vice versa.*
• *Consensus has been reached on accepted indications for referral*
• *Agreed technical standards are used by most cardiac CT providers.*

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Keywords Cardiac · Computed tomography · Cardiac · Survey · Examination technique · Indications

Introduction

Recent technical advances in computed tomography (CT) have dramatically improved CT examinations of the heart. Cardiac CT is now discussed for a variety of indications including noninvasive coronary angiography, for ruling out significant coronary artery disease (CAD), and follow-up after cardiac surgery and coronary stent implantation [1–5]. Moreover, cardiac CT provides morphological information and facilitates the evaluation of global and regional cardiac function (cardiac valves, perfusion, and vitality) [6–8]. Numerous scientific articles published in recent years testify to the intense research activities in the field of cardiac CT [5, 9–16].

The diagnostic versatility has led to a considerable increase in the number of cardiac CT examinations performed and the number of centres providing this service [17, 18]. The infrastructure is not the same in all countries. While the majority of clinical studies are conducted at university hospitals, cardiac CT examinations are also performed by many general and specialised hospitals and office-based radiologists. This may have led to some diversification regarding the technical conduct of cardiac CT (i.e., indications, patient preparation, technical parameters used, type of CT on which the examination is performed), and interpretation and reporting of findings. Because of the numerous factors playing a role in cardiac CT studies, we sought to assess current practice characteristics for each part of the examination. We therefore conducted a questionnaire survey to obtain an overview of how routine diagnostic cardiac CT is currently performed worldwide.

Materials and methods

To obtain an overview of the current worldwide clinical practice of cardiac CT we developed a 32-item four-page questionnaire covering the major aspects surrounding this diagnostic test (Table 1). The questionnaire (with a stamped self-addressed envelope, anonymity ensured) was mailed to a total of 750 providers of cardiac CT in 57 countries worldwide in 2009 (Table 2). The addressee included members of the Society of Cardiovascular Computed Tomography (SSCT) and speakers of the cardiac CT sections at the conferences of the Radiological Society of North America (RSNA) and the European Congress of Radiology (ECR) in the years 2008 and 2009.

The items asked about indications, imaging technique, reading, data storage, and charges. As an incentive for completing the questionnaire, all participants were invited to enter a draw for the educational book *Coronary CT Angiography.*

The first questions pertained to the facility the radiologists work in (university hospital, publicly owned or privately owned hospital, practice, medical service centre), the patients examined by cardiac CT (inpatients, outpatients), the system on which cardiac CT is performed (manufacturer and type), and the number of cardiac CT performed in 2006, 2007, and 2008. The next questions related to the indications for cardiac CT (e.g., exclusion of CAD in patients with intermediate pretest likelihood of disease, bypass follow-up), patient preparation (e.g., administration of sublingual nitroglycerin or betablocker), and technical aspects of the examination (e.g., contrast agent used, start of imaging, tube current adjustment, slice thickness, slice increment, field of view). Other questions referred to the interpretation and reporting of cardiac CT data sets (e.g., overall duration, software tools used) and storage of CT data. The final questions pertained to the percentage of self-pay patients and the total charge for cardiac CT.

Statistical analysis

Categorical data are reported as absolute numbers and percentages. Continous data turned out to be highly skewed and thus are reported as median together with the interquartile range (IQR). Cochran's Q test was used to compare the increase in number of centres performing cardiac CT in 2006, 2007 and 2008. Friedman's test was applied to compare the average number of CT examinations per centre from 2006 to 2008. Successive pairwise comparisons used the Wilcoxon test. Furthermore, a chi-square test was applied to compare the role radiologists and cardiologists play in cardiac CT. An extension of McNemar's test was used to compare the current and the desired roles of respondents in cardiac CT. A p-value of <0.05 was considered significant. Although these are exploratory analyses we used ordered hypotheses to adjust for multiplicity in pairwise comparisons. Statistical analysis was performed with PASW 18 (SPSS Inc.).

Results

The questionnaire was returned by a total of 174 centres (23% response rate) in 38 countries (Table 2 and Fig. 1). Three respondents stated that they do not perform cardiac CT, two questionnaires were incomplete, leaving a total of 169 questionnaires that could be analysed (23% analysis rate).

Participant structure

The 169 respondents (86 radiologists; 68 cardiologists; seven dual-certified; eight not specified) included in the analysis worked in the following facilities: 27% (45/169) in university hospitals, 21% (35/169) in publicly owned or not-for-profit hospitals, 17% (28/169) in a privately owned hospital, 9% (16/169) in their own practices, 8% (14/169) were employed in a practice/medical service centre, and 9% (15/169) worked in more than one institution. Cardiac CT was offered for both inpatients and outpatients by 85% (144/169) of the respondents, only for outpatients by 13% (22/169), and only for inpatients by only one centre. At least one hundred and six of the 169 participating centres (63%) performed cardiac CT examinations in 2006, 135 (80%) in 2007, and 150 (89%) in 2008 (Cochran's Q test 60.04, df=2, $p<0.001$). Only two sites that did cardiac CT in 2006 and 2007 indicated zero

Table 1 Questionnaire and response options

No.	Question	Answers
1	Where do you work (a) and what is your specialty (b)?	(a) University hospital; private-owned hospital; medical practitioner in my own practice; employed physician in a practice; public-owned or nonprofit hospital; (b) Radiology; cardiology, cardiac surgery; other
2	Which patients are examined by cardiac CT in your facility?	Inpatients; outpatients; both
3	Which CT system is used in your facility (multiple answers possible)?	Choice of different numbers of detector rows (4; 6; 12; 16; 32; 32×2; 40; 64; 64×2 128; 128×2; 320) and dual-source CT; Manufacturer and type
4	What are the indications for performing cardiac CT in your facility (multiple answers possible)?	E.g., exclusion of CAD in patients with intermediate pretest likelihood, follow-up of coronary bypass, exclusion of coronary anomaly
5	How many cardiac CT examinations were performed in your facility in 2006–2008 (try to be as accurate as possible, e.g., using the RIS/PACS)?	Numbers in 2006, 2007, and 2008
6	Which constellation best describes the roles of the radiologist and cardiologists in conducting and interpreting cardiac CT examinations in your facility?	e.g. (a) Radiologist: CT imaging and reporting, cardiologist: no role; (b) Radiologist: CT imaging and reporting of extracardiac findings; cardiologist: reporting of cardiac findings; (c) Radiologist and cardiologist: jointly perform the CT imaging and report findings; (d) Radiologist: no role, cardiologist: CT imaging and reporting
7	Which constellation (roles of radiologist and cardiologist) do you consider most suitable for cardiac CT?	E.g. (a) Radiologist: CT imaging and reporting, cardiologist: no role; (b) Radiologist: CT imaging and reporting of extracardiac findings; cardiologist: reporting of cardiac findings; (c) Radiologist and cardiologist: jointly perform the CT imaging and report findings, (d) Radiologist: no role, cardiologist: CT imaging and reporting
8	Do you administer sublingual nitroglycerin before a cardiac CT?	Yes/No; if yes: dose
9	Do you administer a beta blocker before a cardiac CT?	Yes/No; if yes: route of administration and dose
10	Do you use a heart rate threshold above which you administer a beta blocker for lowering heart rate?	Yes/No; if yes: beats/min
11	Do you perform cardiac CT in patients with atrial fibrillation?	Yes/No and reasons
12	Do you test the patient's breath-hold capacity before the CT (e.g., using a breath hold mock examination)?	Yes/No
13	Do you adjust tube current to body weight or BMI?	Yes/No; if yes: how
14	Do you use ECG-triggered tube current modulation?	Yes/No; if yes: up to which heart rate? Do you use step-and-shoot acquisitions (Yes/No)?
15	Which contrast agent do you use?	Manufacturer, trade name, iodine content, flow rate
16	Do you adjust the flow rate of the contrast agent to body weight or BMI?	Yes/No; if yes: how
17	How do you initiate the coronary CT?	E.g., test bolus, visual monitoring of contrast arrival, threshold in ascending/descending aorta
18	Do you use a saline chaser after contrast administration?	Yes/No; if yes: volume and flow
19	What is the reconstructed slice thickness used for cardiac CT data sets?	Thickness in mm
20	What is the slice increment used for reconstruction of cardiac CT data sets?	Increment in mm
21	Do you use small reconstruction field-of-views (FOVs) for cardiac CT data sets?	Yes/No; if yes: size of FOV

Table 1 (continued)

No.	Question	Answers
22	Which phases of the RR interval do you routinely reconstruct for cardiac CT (multiple answers possible)?	5%/10% intervals; motion map; different approach
23	Do you use a workstation that can automatically generate curved MPRs?	Yes/No
24	Which images do you use for interpretation (multiple answers possible)?	E.g., transverse source images, coronal, and sagittal reconstructed images, curved MPRs, 3D volume-rendered reconstructions, thin-slice/thick-slice MIPs, cath views
25	Do you routinely evaluate pulmonary structures and other extracardiac structures using extra reconstructions (on larger FOVs)?	Yes/No, reasons
26	Which images are stored in your facility (multiple answers possible)?	All images, source data set, only cardiac phases used for interpretation and pulmonary reconstructions
27	Where are the images of the cardiac CT examination stored?	PACS/separate server/CD or DVD
28	What is, on average, the estimated duration of a cardiac CT examination (total time patient spends in the examination room)?	Duration in minutes
29	On average, how long do you take for interpretation and reporting?	Duration in minutes
30	What is the total charge for self-pay patients?	Amount in Euros or US Dollars
31	Do you get spontaneous requests from self-pay patients?	Yes/No, if yes: how many per month
32	What is the estimated percentage of self-pay patients?	Percentage

cases in 2008. Twelve sites (7%) did not indicate how many cardiac CT they performed in the years 2006–2008 and additional five sites (3%) started cardiac CT in 2009. Thus there was a significant increase over time. Looking at pairwise comparisons, starting with the increase in number of centres performing cardiac CT in 2007 versus 2006, we found a significant increase ($z=-5.0$, $p<0.001$). Looking at the increase in 2008 versus 2007 we also found a significant increase ($z=-2.6$, $p=0.009$) using ordered hypotheses.

The median annual number of cardiac CT examinations per centre was 50 IQR=500 in 2006 (range, 0 to 3000), 204, IQR=630 in 2007 (range, 0 to 3500), and 300 IQR=730 in 2008 (range, 0 to 5330). Looking at the increase over time we found a significant result of Friedman's test (141.2, df=2, $p<0.001$). Likewise pairwise comparisons between 2006 and 2007 ($z=-5.49$, $p<0.001$) and 2008 versus 2007 ($z=-5.09$, $p<0.01$) turned out be statistically significant.

Four institutions reported separate cardiac CT centres run by radiology and cardiology (Table 3). Regarding the actual roles of radiologists and cardiologists in conducting and reporting cardiac CT examinations, in 43% of the responding centres (66/152) this was done by radiologists, in 31% (47/152) radiologists and cardiologists jointly performed the imaging and the report, and in 9% (13/152) this was done by cardiologists (Table 3). Of the 83 radiology respondents answering this question, 59 centres (71%) were organised in a way that only radiologists took care of cardiac CT. Of the 55 cardiology respondents answering this question, significantly less were organised in a way that only cardiologists took care of cardiac CT (12 [22%]). Based on the the chi-square test this turned out to be statistically significant. (32.14, df=1, $p<0.001$). Interestingly, there was a significant difference between current and desired roles in cardiac CT (Table 3). This was mainly because a relatively large percentage of the 157 respondents (80, 51%) stated that they would prefer radiologists and cardiologists to jointly perform and report the procedure. The detailed responses of radiologists (Table 4) and cardiologists (Table 5) showed that a significant difference between current and desired roles was only present for radiologists.

CT technology

Cardiac CT examinations were performed on systems with different numbers of detector rows (use of multiple systems possible, mean 1.3 systems; range, 1–4): 64-row, 62% (137/221, thereof ten with flying focal spot); 320-row, 7% (16/221); 16-row, 5% (12/221); 32-row, 4% (8/221, thereof five with flying focal spot); 7/221 (3%) were 128-row CT with flying focal spot, and less than 1% 40-row (2/221), 12-row (1/221) and 4-row (1/221). Additionally, 17% (37/221) of the systems used were dual-source CT (DSCT) of which 5

Table 2 Numbers of questionnaires sent to 57 countries and numbers of questionnaires returned from 38 countries

Country	Number of questionnaires sent	Number of questionnaires returned
Argentina	3	1
Australia	30	3
Austria	4	4
Belgium	8	3
Brazil	17	6
Canada	25	9
China	4	2
France	6	4
Germany	14	10
India	5	–
Italy	12	4
Japan	20	12
Mexico	6	2
Netherlands	13	6
New Zealand	8	1
Norway	4	2
Philippines	4	–
Poland	5	1
Saudi Arabia	4	1
South Korea	8	4
Spain	3	2
Sweden	4	1
Switzerland	7	4
Turkey	3	–
UK	50	10
USA	445	43
Venezuela	5	1
Greece, Malaysia, Portugal, Singapore, Taiwan, United Arab Emirates	2 each	Return of 2 questionnaires each from the following countries: Greece, United Arab Emirates, Singapore, Taiwan
Barbados, Chile, Colombia, Czech Republic, Denmark, Dominican Republic, Egypt, Finland, Guatemala, Iran, Ireland, Indonesia, Israel, Kenya, Kuwait, Pakistan, Romania, Russia, Scotland, Slovakia, Thailand, Puerto Rico	1 each	Return of 1 questionnaire each from the following countries: Croatia, Czech Republic, Dominican Republic, Finland, Ireland, Malaysia, Portugal, Romania, Russia, South Africa,
Total	750	169[a]

[a] for 15 questionnaires, the country of origin is not known

of 40 were of the latest second generation (64*2 rows) (Fig. 1).

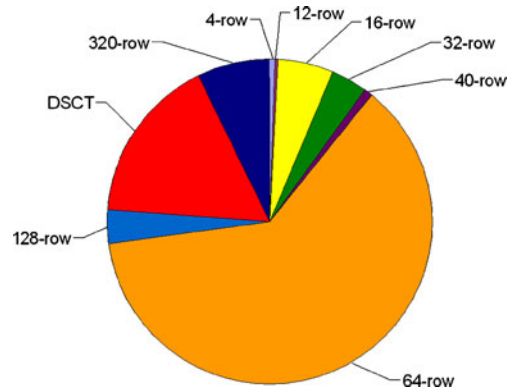

Fig. 1 Distribution of different CT types used for cardiac imaging (n=221): The vast majority of CT systems currently used for cardiac imaging have more than 64 detector rows. Most recent technology including 128-row CT, DSCT, and 320-row CT contribute over 25% of systems used. Ten of the 135 CT with 64 rows and five of the eight scanners with 32 rows had a flying focal spot. All 7 CT with 128 rows had a flying focal spot

Indications

The indications most commonly considered appropriate for cardiac CT were the exclusion of CAD in patients with a low or intermediate likelihood of disease, which was chosen by 97% (164/169) of all participants, the exclusion of coronary anomalies (92%; 156/169), follow-up of patients with coronary bypasses (76%; 128/169), simultaneous exclusion of CAD, aortic dissection, and pulmonary embolism ("triple rule-out"; 44%; 75/169), and analysis of cardiac function as part of CT coronary angiography chosen by 44% (75/169; Table 6).

Moreover, cardiac CT examinations were performed for the exclusion of CAD in clinically healthy patients by 34% (58/169) of the centres, for follow-up of patients with coronary stents depending on the stent diameter (33%; 56/169; median 3 mm; range, 2.0–4.0 mm), for suspected CAD in patients with high pretest likelihood of disease (33%; 55/169), for acute coronary syndrome or unstable angina (21%; 36/169), for follow-up of patients with coronary stents regardless of stent diameter (21%; 35/169), for analysis of cardiac function as an independent examination (11%; 19/169), and for analysis of myocardial viability and perfusion (11%; 19/169). Other indications mentioned for cardiac CT were calcium scoring, evaluation of pulmonary veins prior to ablation, evaluation of pericardial disease, analysis of valves in patients with inconclusive echocardiography, preoperative evaluation before valve surgery, and screening of asymptomatic patients before liver transplantation.

CT technique

A beta blocker was given by 151 of 166 respondents (91%). Of those who provided further details (n=149), 47

Table 3 Differences between current roles of radiologists and cardiologists and desired roles in the cardiac CT centres

		Current role of Radiologists and Cardiologists							Sums:
		No answer provided	Radiologist: imaging and reporting, cardiologist: no role	Radiologist: imaging and reporting of extracardiac findings; cardiologist: reporting of cardiac findings	Radiologist and cardiologist: jointly perform the CT imaging and report findings	Radiologist: imaging, cardiologist: reporting	Radiologist: no role, cardiologist: CT imaging and reporting	Separate cardiac CT facilities run by radiology and cardiology	
Desired role of Radiologists and Cardiologists	No answer provided	6	6	0	0	0	0	0	12
	Radiologist: imaging and reporting, cardiologist: no role	0	42	0	1	0	0	1	44
	Radiologist: imaging and reporting of extracardiac findings; cardiologist: reporting of cardiac findings	4	1	13	3	1	1	0	23
	Radiologist and cardiologist: jointly perform the CT imaging and report findings	6	17	5	42	2	7	1	80
	Radiologist: imaging, cardiologist: reporting	0	0	0	1	1	1	0	3
	Radiologist: no role, cardiologist: CT imaging and reporting	1	0	0	0	0	3	0	4
	Separate cardiac CT facilities	0	0	0	0	0	1	2	3
Sums:		17	66	18	47	4	13	4	169

McNemar's test showed that there was a significant difference (46.06, df=15, $p<0.001$) between current practice and the desired roles. The grey boxes indicated similar choices between current practice and desired roles. In contrast, the underlined figures show the major deviations

(32%) gave an intravenous beta blocker only (mostly metoprolol; median 15 mg; range, 5–75 mg), 40 (27%) only an oral beta blocker (mostly metoprolol; median 40 mg; range, 2.5–150 mg), and 62 (42%) gave an oral followed by an intravenous beta blocker (oral metoprolol at a median dose of 100 mg (range, 5–200 mg) followed by intravenous metoprolol at a median dose of 15 mg (range, 5–100 mg). One hundred fifty five of 168 respondents (92%) used a heart rate threshold above which they administered a beta blocker for lowering heart rate (median 65 beats/min; range, 60–90 beats/min). Administration of sublingual nitroglycerine prior to cardiac CT was routinely done by 80% (134/168) of the participants (median of 1 mg; range, 0.1 mg–5 mg; median of 2 sprays=0.8 mg; range, 1–4 sprays; Table 7). The majority of respondents stated that they performed cardiac CT in patients with atrial

Table 4 Differences between current and desired roles as viewed by radiologists

		Current role of Radiologists and Cardiologists			Sums:
		Radiologist: imaging and reporting, cardiologist: no role	Radiologist: imaging and reporting of extracardiac findings; cardiologist: reporting of cardiac findings	Radiologist and cardiologist: jointly perform the CT imaging and report findings	
Desired role of Radiologists and Cardiologists	Radiologist: imaging and reporting, cardiologist: no role	39	0	1	40
	Radiologist: imaging and reporting of extracardiac findings; cardiologist: reporting of cardiac findings	0	2	0	2
	Radiologist and cardiologist: jointly perform the CT imaging and report findings	15	3	16	34
Sums:		54	5	17	76

McNemar's test showed that there was a significant difference (15.25, df=2, $p<0.001$) between current practice and the desired roles with an increase of joint imaging and reporting suggested. The grey boxes indicated similar choices between current practice and desired roles. In contrast, the underlined figures show the major deviations

fibrillation (AF, 60%; 100/167); of these, 33 used dual-source CT, 9 a 320-row, and 41 a 64-row CT. 40% (67/167) of the participants stated they did not examine patients with AF. The reason given for not performing cardiac CT in this group of patients was that the high radiation dose did not justify an examination that might not yield the desired diagnostic information. However, those respondents who performed cardiac CT in patients with atrial fibrillation reported that the image quality was sufficient in this subgroup. The patient's breath-hold capacity was tested in a mock examination by 76% (128/168) of respondents before the imaging; 63% of these (78/123) used the heart rate and heart rate variability determined in this test to adjust the imaging parameters (e.g., gantry rotation time, pitch). The tube current was adjusted to the patient's body weight or body mass index by 79% (130/165). One hundred and thirty of 165 participants (79%) used ECG-triggered tube current modulation for a median heart rate of up to 80 beats/min (range, 50–100 beats/min). Prospectively triggered "step-and-shoot" acquisition was used by 55% (90/165) up to a median heart rate of 80 beats/min (range, 55–110 beats/min). The contrast agents used by the respondents included different commercially available preparations with a median iodine content of 350 mg/ml (range, 300 to 400 mg/ml); the median flow volume reported was 5 ml per second (range, 3.5–8 ml/s). About 40% of the participants (68/166) stated that they adjusted the injection rate to the patient's body weight or body mass index. Different modes of determining the imaging delay and initiating the image acquisition were described (multiple answers possible): 56% (92/165) used the bolus tracking method with start of the imaging once a threshold value is reached, 42% (69/165) used the test bolus method to determine individual circulation time, and 9% (15/165) started the imaging after bolus administration and contrast arrival in the target area was noted visually. The median threshold for bolus tracking used was 150 HU with a range of 50 to 300 HU, and the most common site for measurement was the ascending aorta (59%, 43/73), while 41% (30/73) used the descending aorta. Nearly all participants (164/169, 97%) stated that they administered a saline chaser following intravenous contrast injection (median amount of saline of 50 ml; range, 10–100 ml; median flow rate, 5 ml/s; range, 0.5–8 ml/s). The estimated average duration of a cardiac CT examination (time the patient spent in the examination room) was 18.6±8.4 min (median 15 min; range, 5–60 min).

Reconstruction and reading

A median slice thickness of 0.625 mm (range, 0.5–2 mm) with a 0.5-mm increment (range 0.2–4 mm) and a small reconstruction field-of-view with a median size of 18 cm (range, 12–50 cm) was most commonly used (Table 8). 43% (71/164) of the participants routinely used the phases

Table 5 Differences between current and desired roles as viewed by cardiologists

		Current role of Radiologists and Cardiologists					Sum
		Radiologist: imaging and reporting, cardiologist: no role	Radiologist: imaging and reporting of extracardiac findings; cardiologist: reporting of cardiac findings	Radiologist and cardiologist: jointly perform the CT imaging and report findings	Radiologist: imaging, cardiologist: reporting	Radiologist: no role, cardiologist: CT imaging and reporting	
Desired role of Radiologists and Cardiologists	Radiologist: imaging and reporting, cardiologist: no role	0	0	0	0	0	0
	Radiologist: imaging and reporting of extracardiac findings; cardiologist: reporting of cardiac findings	1	10	3	1	1	16
	Radiologist and cardiologist: jointly perform the CT imaging and report findings	1	2	21	1	6	31
	Radiologist: imaging, cardiologist: reporting	0	0	0	1	1	2
	Radiologist: no role, cardiologist: CT imaging and reporting	0	0	0	0	3	3
Sum		2	12	24	3	11	52

McNemar's test showed that there was a trend but no significant difference (11.20, df=7, p=0.130) between current practice and the desired roles. The grey boxes indicated similar choices between current practice and desired roles. In contrast, the underlined figures show the major deviations

from 0% to 90% in 10% intervals from the RR interval for reconstruction, 9 (5%) used 5% intervals, 53 (32%) used a single interval at a median of 75% (range, 10–80%), and 31 (19%) used motion mapping. A workstation capable of automatically generating multiplanar reconstructions (MPRs) was used for interpretation by 75% (122/163) of the respondents. The following images were used for interpretation in decreasing order (multiple answers possible): transverse source images or coronal and sagittal reconstructed images (92%, 155/169 of participants), curved MPRs (87%, 147/169), thin-slice maximum intensity projections (MIPs) (70%, 119/169), 3D volume-rendered reconstructions (56%, 95/169), thick-slice MIPs (29%, 49/169), angiographic emulations (19%, 32/169) [19], and cath views (12%, 20/169). The total average time required for interpretation and reporting was 28.7±17.8 min (median 20 min; range, 5–120 min).

One hundred and eighteen of 168 (70%) participants routinely evaluated pulmonary and other extracardiac structures using extra reconstructions on larger field-of-views; another 35 participants did this only on cardiac field-of-views (20%). Fifteen participants (9%) stated that they did not evaluate extracardiac structures because they were not the primary concern of the examination or

Table 6 Indications for cardiac CT deemed suitable by the participating centres

Indications	Percentage (number) of respondents
Exclusion of CAD in patients with low or intermediate pretest likelihood of disease	97% (164/169)
Exclusion of coronary anomalies	92% (156/169)
Follow-up of patients with coronary bypass	76% (128/169)
Simultaneous exclusion of CAD, aortic dissection, and pulmonary embolism (“triple rule-out”)	44% (75/169)
Analysis of cardiac function as part of CT coronary angiography	44% (75/169)
Exclusion of CAD in clinically healthy patients	34% (58/169)
Follow-up of patients with coronary stents according to stent diameter (median 3 mm; range, 2–4 mm)	33% (56/169)
Suspected CAD in patients with high pretest likelihood of disease	33% (55/169)
Acute coronary syndrome or unstable angina	21% (36/169)
Follow-up of patients with coronary stents regardless of stent diameter	21% (35/169)
Analysis of cardiac function as an independent examination	11% (19/169)
Analysis of myocardial viability and perfusion	11% (19/169)

Other indications mentioned: calcium scoring, evaluation of pulmonary veins prior to ablation, evaluation of pericardial disease, analysis of valves in patients with inconclusive echocardiography, preoperative evaluation before valve surgery, screening of asymptomatic patients before liver transplant

because of time constraints. There was no significant difference in the frequency of reading of extracardiac findings (on either large or cardiac field-of-views) between radiology (94% [80/85]) and cardiology sites (88% [58/66]). However, significantly more cardiologists than radiologists used the cardiac field-of-view only for reading extracardiac findings (p=0.005; 30% [20/66] vs. 12% [10/85]).

Data storage

Fifty-three percent (90/168) of respondents stored image data only in a PACS, 15% (26/168) in a PACS and additionally on an additional server; 15 (9%) only on an additional server and 11 (7%) only on CD or DVD, and 15 (9%) in a PACS and additionally on CD/DVD. All images obtained were stored by 52% (79/153) of participants; 55 of 153 participants (36%) stored the cardiac phases used for interpretation and the pulmonary reconstructions, and 19 participants (13%) only the cardiac phases used for interpretation.

Charges

Spontaneous requests from self-pay patients were reported by 37% (61/163) of the participants. The average monthly number of such requests was 7.9 (range, 0.5–50). The average proportion of self-pay patients per centre was 16.7% (range, 0–100%). An average charge of 642±568 EUR (range 89–4074 EUR) was reported for self-pay patients.

Discussion

To our knowledge this is the first extensive study investigating routine clinical cardiac CT in terms of current indications, imaging protocols, image reconstruction and interpretation, and charges. The return of the questionnaires we sent to countries all over the world resulted in a moderate analysis rate of 23% (169/750). The analysis of the questionnaire survey reveals a significant increase in the cardiac CT examinations and the number of centres that performed cardiac CT over the years, reflecting the growing role of this investigation. Our survey shows, on a worldwide perspective, that cardiac CT has become established in clinical practice, and standards have emerged regarding indications, conduct of the CT, and reconstruction as well as reporting of the images.

Our questionnaire also indicates that radiologists are involved in performing and interpreting cardiac CT to a greater extent than cardiologists. There was a discrepancy between the actual and desired practice of performing and interpreting cardiac CT indicating great interest in collaborations. Radiology sites are, however, significantly more interested in jointly performing cardiac CT together with cardiologists than Cardiology sites are. This is interesting against the background that many cardiac imaging procedures like echocardiography and cardiac catheterization have their roots in radiology but are now mostly performed by cardiologists. Cardiac CT is changing this dynamic. Therefore, radiologists, who are the experts in CT and CT angiography which also includes all aspects of cardiac CT imaging are capable of performing this test independently and recognize this as an opportunity to regain turf in cardiac imaging. In addition, the desired role of radiologists

Table 7 Parameters used for cardiac CT

Parameter	Percentage (number) of respondents	Median	Minimum	Maximum
Sublingual nitroglycerin	80% (134/168)	2 sprays=0.8 mg	1 spray=0.4 mg	4 sprays=1.6 mg
Beta-blocker	91% (151/166)	oral metoprolol only: 40 mg	2.5 mg	150 mg
		IV metoprolol only: 15 mg	5 mg	75 mg
		oral and IV metoprolol combined: 100 mg oral, 15 mg IV	5 mg oral, 5 mg IV	200 mg oral, 100 mg IV
Heart rate threshold for beta blockade	92% (155/168)	≥ 65 beats/min	≥ 60 beats/min	≥ 90 beats/min
Examination of patients with atrial fibrillation	60% (100/167)			
Testing of breath-hold capacity before the imaging	76% (128/168)			
Adjustment of tube current to body weight/BMI	79% (130/165)			
ECG-triggered tube current modulation	79% (130/165)			
Iodine content of contrast agent		350 mg/ml	300 mg/ml	400 mg/ml
Contrast agent flow volume in ml/s		5 ml/s	3.5 ml/s	8 ml/s
Start of CT using bolus tracking and threshold used	56% (92/165)	150 HU	50 HU	300 HU
Start of CT using test bolus method	42% (69/165)			
Saline chaser after contrast agent injection: amount and flow	97% (164/169)	50 ml	10 ml	100 ml
		5 ml/s	0.5 ml/s	8 ml/s
Estimated total duration of cardiac CT examination		15 min	5 min	60 min

was to a greater extent than the current role one of joint performance and reporting.

The high proportion of respondents from hospitals (108/169; 64%) explains the large number of those who perform cardiac CT examinations in both inpatients and outpatients.

Indications

A guideline for cardiac CT jointly published by several radiology and cardiology societies with a focus on cardiac imaging [1] lists 39 possible indications for cardiac CT examinations and classifies 13 as appropriate, 12 as uncertain, and 14 as inappropriate. The indications considered to be appropriate include the detection of asymptomatic coronary artery disease (CAD) with intermediate pretest likelihood and suspected coronary anomalies, while detection of CAD in patients with low pretest likelihood of disease is considered an uncertain indication. An example of an inappropriate indication is the detection of CAD in patients with proven mild to severe ischemia. The majority of indications for which cardiac CT examinations were performed by the participating centres are among those classified as appropriate in the guidelines. However, the fact that 34% of all participants perform screening cardiac CT for exclusion of CAD in clinically asymptomatic patients might reflect an undesirable trend of aggressive marketing of coronary CT as a part of so-called health check-ups. As this is an inappropriate indication it may even be illegal as many countries allow the use of X-rays for screening only if the benefit of the examination outweighs its potential damage. It is still unclear whether coronary CT angiography actually has advantages over other modalities for the screening of asymptomatic patients with cardiac risk factors.

CT imaging and technique

Most CT used for cardiac imaging were systems of a newer or the newest generation as 170 CT (77%) had at least 64 detector rows and 37 (17%) were DSCT. Importantly, 16 and 5 CT, respectively, were 320-row CT and DSCT with a 'high pitch' mode that greatly reduces doses. Nevertheless, cardiac CT is still considered a challenge in patients with a high or irregular heart rate. In fact, the high temporal resolution of DSCT reduces the susceptibility to motion artifacts [20–22]. The 100 respondents who stated that they performed cardiac CT also in patients with AF used dual-source CT in 33 facilities and 320-row CT in nine centres. However, a sufficient robustness for examinations of patients with AF even with the latest CT generation has not been shown yet. It was also distressing that there was also a large proportion of respondents who performed cardiac CT in patients with AF (25%) in facilities where the best system available was a 64-row CT which may be considered an inappropriate indication in this situation.

Table 8 Techniques used for image reconstruction, interpretation, and reporting

Parameter	Percentage (number) of respondents	Median	Minimum	Maximum
Slice thickness		0.625 mm	0.5 mm	2 mm
Increment		0.5 mm	0.2 mm	4 mm
Size of reconstruction FOV		18 cm	9 cm	50 cm
Use of transverse source images or coronal and sagittal recontructed images for interpretation	92% (155/169)			
Use of curved multiplanar reformations for itnerpretation	87% (147/169)			
Use of thin-slice maximum intensity projections for interpretation	70% (119/169)			
Evaluation of extracardiac structures	91% (153/168); thereof 35/168 only on cardiac FOV			
Total time for interpretation and reporting		20 min	5 min	120 min

Beta-blockers are the first-line option for short-term reduction of the heart rate in patients undergoing coronary CT angiography [23]. In a survey in the United States, Johnson et al. found that all centres (100%) administered beta-blockers for heart rate reduction prior to the examination; in more than the half (53%), the oral route of administration was supplemented by IV [24]. In our study, a beta blocker was given by 91% of all centres, whereas an additional IV administration was reported by 42%. The majority of respondents (80%) stated that they administer sublingual nitroglycerin before the imaging which is similar to the survey in the United States (84%, [24]) and to a survey from Germany (84%, [18]). Nitroglycerine widens the coronary arteries and may thus improve comparison with cardiac catheterisation [25]. It may also help in differentiating true lesions from temporary spasms of the coronary arteries [26]. However, one must be aware that the combination of nitroglycerine and beta blockers can very rarely cause reflex tachycardia and hypotension.

We found that only about three quarters of the participants (76%) practiced breath-holding with the patient before the examination. This is somewhat surprising since it was shown that good diagnostic image quality can be achieved if the imaging parameters are adapted based on the heart rate during a breath-hold exam simulation and if a patient can properly hold his or her breath during the actual imaging [27].

Although uniform and strong enhancement is crucial for the evaluation of the coronary arteries, there is as yet no general recommendation regarding the most suitable protocol for intravenous contrast medium administration. The results of several studies suggest that the use of a contrast agent with an iodine content of 350–400 mg/ml administered at a flow rate of 4–6 ml/s appears to be suitable for achieving the desired enhancement [9, 28, 29]. The reported practice in our survey corresponds to these scientific results with a median iodine content of the contrast agents of 350 mg/ml and a median flow rate of 5 ml/s. Nearly all respondents (99%) stated that they used one of the two established techniques for initiating the imaging, either test bolus administration for determining individual circulation time (42%) or bolus tracking (56%) [30, 31]. The preference for bolus tracking can be attributed to the superior image quality resulting from more uniform enhancement, as demonstrated by Cademartiri et al. [31]. Nearly all centres (98%) use a saline chaser following contrast medium injection because it improves image quality. The main effect of a saline chaser is the reduction of artifacts that might otherwise result from high amounts of contrast medium in the right atrium and ventricle [32, 33].

Interpretation and reporting

The participants aim at an efficient workflow in image interpretation and reporting. Three quarters use special software tools for analysis (e.g., for automatic generation of curved MPRs), which considerably facilitate reading [34, 35]. As expected, the time required for interpretation and reporting decreased with an increasing number of examinations performed by a centre. The median time for interpretation and reporting is 20 min, and a training effect is clearly obvious from the fact that reading took 120 min in the facility examining only 20 patients in 2007 as opposed to 5 min in the facility examining 2000 patients.

More than 90% of participants evaluated extracardiac structures as well. This clearly contradicts a recent statement that most radiologists performing cardiac CT do not do so because the heart is of primary concern in the examination [36]; however, 35 respondents (20%) in our survey used only the cardiac field of view for evaluating extracardiac structures. Significantly more cardiologists than radiologists were among those who used the cardiac field of view only for reading extracardiac findings. There is an ongoing debate about the benefit of evaluating extracardiac structures [37–39] because it is still unclear whether reconstructions of large field of views would be effective in prolonging life. However, it could be considered to be unethical not to evaluate extracardiac structures at all due to time constraints as six participants stated. The evaluation of extracardiac structures on cardiac CT may reveal relevant pathology requiring immediate therapeutic management such as pulmonary artery embolism, aortic dissection, or pulmonary masses [36]. According to our results with 90% of the sites routinely searching for extracardiac findings the debate is not so much one of whether or not to look for extracardiac findings but to do this on large (70%) or cardiac field of views (20%).

Data storage and charges

Most centres stored CT data in a PACS and/or on an additional server (78%). Over the last years, PACSs have become a standard, which may also help in improving cooperation with other specialties such as cardiology [40]. Nevertheless, minimising costs also plays a role, and only slightly more than half the respondents (52%) archive all images generated, while 48% store only those image data that are relevant for interpretation.

Cardiac CT is a relatively new diagnostic option but already appears to be known to the general population. This is suggested by a considerable number of spontaneous requests from self-pay patients, which is reported by 37% of the respondents. Nevertheless the proportion of examinations performed in self-pay patients is still low in relation to the total number of examinations performed (approx. 100 per centre and year versus an average of 701 cardiac CT examinations per centre in 2008). The average reimbursement of 642 EUR per examination reported in our survey appears to be adequate when one takes into the considerable investment for CT and expenses for staff and disposables. However, there were also exceptions, and a reimbursement of 4074 EUR appears to be excessively high.

Limitations

Our study has some limitations. It is always desirable to have a large number of respondents. However, physicians are less likely to participate in a survey due to their heavy workload. Our return rate of 23% (174/750; 23% analysis rate, 169/750) is only moderate and slightly below the return rates achieved in national surveys [18, 24]. Nevertheless, it corresponds to the expected return rate of questionnaire surveys reported by Jepson et al. [41]. Because information about the specialty of physician in the databases was not available we are not able to calculate specialty-based return rates. One must also be aware that it is technically much more difficult to achieve a high response rate in a worldwide survey, in our case involving returns from 38 countries. Some bias may have resulted from the fact that mainly academic and hospital-based physicians and more radiologists participated in the survey. Significantly fewer office-based colleagues returned the questionnaires, possibly because economic considerations and time constraints play an even greater role in private practice. The responses to desired roles of radiologists and cardiologists may have been influenced by the radiology association of the authors. We cannot claim that our data provide a comprehensive overview of the current practice of cardiac CT worldwide, but our study nevertheless provides interesting insights into the different practical aspects of its routine use. We focused on the major fields of application of cardiac CT and other, less commonly performed examinations as in the field of congenital heart disease, were not specifically included in the questionnaire. Tube current modulation and prospectively triggered data acquisition were asked for as measures to reduce radiation exposure while tube voltage reduction was not included.

Ongoing technical developments will continue to improve cardiac CT in the years to come. The increasingly wider availability of CT of the latest generation (320 detector rows, ‘high pitch’ DSCT), which minimise motion artifacts resulting from the beating heart by providing excellent spatial resolution and very short imaging times, led to a wider use of cardiac CT in patients with high heart rates or atrial fibrillation in our survey. However, performing cardiac CT in patients with atrial fibrillation is considered inappropriate [4].

It remains to be seen whether CT will outperform alternative cardiac imaging investigations and become the first-choice for the evaluation of further congenital, ischaemic, and acquired heart conditions. A further reduction of the radiation exposure will be pivotal for the even wider use of cardiac CT.

Conclusion

The results of our survey show that cardiac CT has rapidly become adopted with increasing numbers of examinations performed each year. The results indicate that appropriateness criteria as well as performance standards for cardiac CT have started to become established in clinical practice.

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