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Coronary CT is overused, angiography remains the standard[1]

Summary

Computerised tomography (CT) was first used to screen for coronary artery disease (CAD) by using a calcium score produced by electron beam computerised tomography (EBCT). After an initial boom, the interest waned until CT angiography became available with 16- and more recently 64-slice technology. Stunning pictures of the major epicardial coronary arteries can be produced and luminal narrowings can be reconstructed. However, the enthusiasm of those running such equipment is not justified for a number of banes of the technique. First, the coronary arteries can be seen at best down to the second-degree vessels. Smaller vessels do simply not appear on the pictures. Second, there are plenty of artefacts. Even if they are recognised as such, each of them renders a segment of the coronary tree non-assessable. Third, calcium (virtually omnipresent in people beyond 50 years of age) forfeits analysis of the vessel adjacent to it. Forth, the heart rate needs to be regular and in the physiological range for any gating process. Fifth, the patients have to be able to hold their breaths for 15–30 seconds while constrained in an uncomfortable position and surrounding. And last but not least the radiation dose applied is prohibitive for a screening method. Irradiation is higher than for a conventional coronary angiogram including multivessel angioplasty. There is hope, that radiation can be reduced by dual source CT apparatus or prospective ECG gating. Yet, even if the x-ray hazard can be significantly curbed, the method remains invalidated by oversensitivity. Most people in the typical screening ages will have irregularities in CT coronary angiography. Hence, they will all be sent on to conventional coronary angiography so that the intermediate step of CT angiography should be skipped. In young people, where normal coronary arteries prevail, CT angiography screening for CAD will produce a malignant tumor in about 1 out of 200 cases. This being conveyed to people asking for it will likely stop them asking for it.

Key words: coronary angiography; CT angiography; coronary artery disease; radiation exposure

Historical development

Selective coronary angiography started on October 30th, in 1958, when Mason Sones inadvertently injected dye directly into the right coronary artery of a patient rather than into the ascending aorta as customary at the time (fig. 1) [1]. The quality of the picture was certainly not up to today's standards. Nonetheless, it is superior to the current resolution of computerised tomography (CT) angiography.

Interest for CT technology in context with coronary artery disease first rose more than 10 years ago when electron beam computerised tomography (EBCT) was advocated for screening for coronary calcifications pinpointing clinically relevant coronary artery disease [2]. The technique boomed for a while in com-

Figure 1
First selective coronary angiogram of 1958.

1 This article summarises a lecture at the annual meeting of the Swiss Society of Cardiology in Geneva, June 2007.

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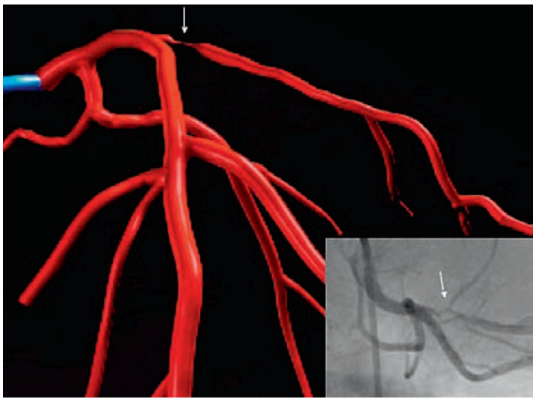

Figure 2
Tight lesion (arrow) in the left coronary artery shown by traditional angiography (insert) and 3-dimensional reconstruction using conventional modern X-ray equipment.

mercially oriented medical environments. It practically always found "disease" in the population interested in the test, ie, middle-aged (mostly affluent) men worried about their risk for myocardial infarction. It has long been known to cardiologists and eventually also to the remainder of the doctors that calcium in the wall of the coronary arteries be part of aging as are wrinkles in the face. Performing EBCT was a win-win situation that did, however, carry the risk of exploding healthcare costs. The patients were typically first alarmed but in most cases this was unveiled as false alarm with subsequent tests, be they exercise stress electrocardiography, myocardial scintigraphy, or coronary angiography. The patients (nonpatients that is) easily reconciled with the initial exam although it had lifted the flag for all the wrong reasons. They felt like having been given a second life by the subsequent tests acquitting them from the verdict of coronary artery disease. The few in whom real disease was found were even more pleased with the CT test as they regarded it as a life saviour having uncovered the problem in time for being taken care of before irreversible damage occurred.

The industry once launched was unstoppable. First 4-slice CT angiography ensued, then 16-slice, then 64-slice, now 256-slice or double source, and this is not the end. The relief depictions of the coronary tree conjuring up 3-dimensionality were true eye catchers. Easily people were distracted from the fact that only the main vessels were seen, artefacts abounded, the lumen (what really keeps the patients alive) was less conspicuously seen, and finally, angiography could rival CT in terms of plasticity and colour (fig. 2) but did not have to because it had better things to offer.

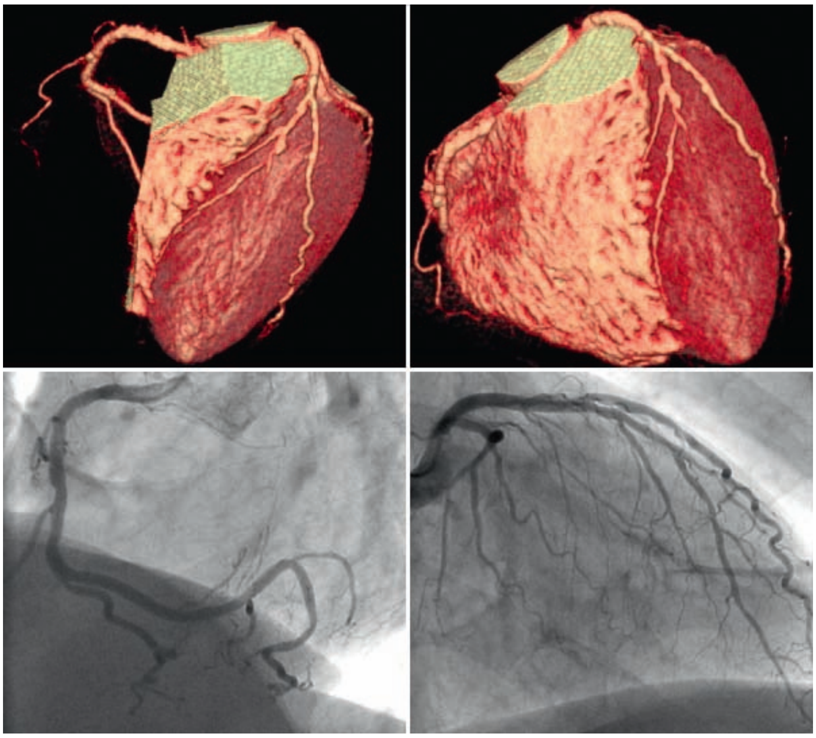

Figure 3
Top: CT done for screening for coronary artery disease in a 54-year-old asymptomatic Hungarian business man who was subsequently urgently flown to Switzerland for immediate angiography and therapy.
Bottom: Angiography revealed only minor wall irregularities and uncovered the CT as blatantly false positive.

Technicalities

The main advantage of angiography consists in the fact that it projects the entire heart onto a plane, thereby lossless reducing 3 dimensions to 2 dimensions. Every picture point is placed in an analogue fashion. Its position is therefore unaltered and genuine. Computerised pictures, be they from CT or magnetic resonance (MR) are also 2-dimensional. Yet, they are recalculated from a number of slices (0.5 mm) cut through the object. As the picture should be real-time or at least close to, powerful computers are required. On one hand, they can add a 3-dimensional flair to the picture; on the other hand, they are bound to miscalculate and creating pixel displacements or even gross artefacts. Figure 3 depicts, what happens, when a CT shows what is not really there which is rather the rule than the exception.

Diagnostic performance

Table 1 [2–23] depicts results of a selection of studies comparing coronary CT to the gold standard, ie, coronary angiography. Even abstracting from the fact, that angiography is possible in all patients while CT can only be done in patients capable of holding their breaths for about 20 seconds while being in a fairly slow sinus rhythm, specificity and positive predictive value of CT are severely handicapped by artefacts such as the ones in the case of figure 1. A comparative study between the Siemens Sensation 64-slice and the Toshiba Aquilion 64-slice equipment in 150 and 42 patients, respectively, showed comparable but poor positive predictive values of 46% and 40%, respectively [24].

Associated techniques

Functional techniques can be associated to coronary angiography with table mounted bicycle exercise testing, flow velocity measurements, pressure assessments, and detailed collateral studies. CT has been combined with stress single photon emission computed tomography (SPECT) or positron emission tomography (PET) [25] depicting myocardial perfusion or viability. These two informations are not obtainable by conventional angiography. However, those adjunctive methods can be combined with angiography serially.

Hazards and complications

The complications of diagnostic coronary angiography have been estimated at a mortality of 0.05% and a rate of significant cardio-cerebral complications of 0.4% around 1990 in over 20 000 patients [26, 27]. The respective figures around 2000 in an equally large patient population were 0.03% and 0.05% [28]. Both procedures require a venous access, CT for contrast administration, angiography (in most laboratories) for safety reasons and for injection of auxiliary drugs. Angiography in addition requires an arterial access that, admittedly, can cause local problems all of which may not necessarily show up in complication data banks. CT, on the other hand, is subject to problems like claustrophobia and poor collaboration in terms of breath holding and fidgeting. Both procedures can be done within a few hours in out-patients. Angiography requires some post interventional surveillance.

The contrast medium load in terms of quantity and toxicity is comparable. For CT, 80 ml to 130 ml are standard. It is easier to reduce contrast medium with conventional an-

Table 1
Quality of CT coronary angiography.

Author	year	patients	sensitivity*	specificity*	positive predictive value*	negative predictive value*
16-slice						
Kopp [3]	2002	102	93%	97%	81%	99%
Nieman [4]	2002	58	95%	86%	90%	97%
Burgstahler [5]	2003	10	86%	100%	75%	86%
Ropers [6]	2003	77	92%	93%		
Achenbach [2]	2004	22	82%	86%	91%	76%
Hoffmann [7]	2004	33	63%	96%	64%	96%
Kuettner [8]	2004	60	72%	97%	72%	97%
Martuscelli [9]	2004	93	97%	100%		
Mollet [10]	2004	128	92%	95%	79%	98%
Schlosser [11]	2004	48	96%	95%	81%	99%
Achenbach [12]	2005	50	100%	83%		
Hoffmann [13]	2005	103	95%	98%	87%	99%
Kaiser [14]	2005	149	85%	50%	78%	62%
Schuijf [15]	2005	45	85%	89%	71%	95%
Schuijf [16]	2005	31	93%	96%	88%	98%
Burgstahler [17]	2006	13	83%	93%	89%	100%
Garcia [18]	2006	238	89%	65%	13%	99%
Andreini [19]	2007	61**	99%	96%	81%	100%
Mean* **		**1321**	**90%**	**84%**	**65%**	**93%**
64-slice						
Leber [20]	2005	55	73%	97%		
Leschka [21]	2005	67	94%	97%	87%	99%
Raff [22]	2005	70	86%	95%	66%	98%
Pugliese [23]	2006	35	99%	96%	78%	99%
Mean* **		**227**	**87%**	**96%**	**77%**	**99%**

* Analysis by segment. ** Patients with dilated cardiomyopathy.
*** Adjusted for number of patients studied.

giography than with CT-angiography. With biplane equipment, 3 coronary injections (1 right and 2 left) of 10 ml each and a left ventricular injection of 15 ml suffice, amounting to a total of 45 ml.

The positive and negative sides of the competing techniques are depicted in table 2 [18, 29, 30].

Radiation exposure

Simple calcium scoring imparts 1–2 mSv on the patient [31]. However, calcium scoring has been abandoned because calcium is invariably present in people older than 50 years and it is difficult to create an algorithm that tells significant (relevant for lumen) from insignificant (eg, adventitial) calcifications. The recent report showing a good correlation of coronary calcification detected by CT with all-cause mortality appears rather trivial, irrespective of the adjustment for age [32]. Calcification (not unlike grey hair) is a surrogate of biological (not necessary chronological) aging and therefore impending death. For a multislice coronary angiography, at least 10 mSv have to be invested, with the current 64-slice machines the exposure approaches 20 mSv. This is bound to increase when moving to 256-slice equipment although the use of a dual source may curb the radiation exposure somewhat. Conventional coronary angiography (monoplane or biplane) ranges in the realm of 5 mSv [33]. This allows adding therapy (percutaneous coronary intervention) and still staying below the radiation dose of CT angiography. For comparison, men are exposed to an annual dose of about 2 mSv from natural sources and radiation workers are monitored not to exceed a dose of 15 mSv per year [31]. Combining CT angiography with a functional test such as SPECT or PET doubles the dose to 30–40 mSv. Applying this combined technique (fig. 4) raises ethical questions considering the fact that radiation-free alternatives are available for the functional part (MR and stress or exercise echocardiography) and the anatomical information can be collected with $1/10^{th}$ of the dose.

It has been calculated, that screening about 600 patients with multislice CT coronary angiography will produce one new malignancy. This number increases if the screening field is enlarged (venous or particularly mammary artery bypass grafts) or functional tests are associated. Breast cancer in women is the most common tumor produced. It can be calculated that one in 150 20-year-old women subjected to a 64-slice CT for screening for coronary artery disease (not a likely scenario) will pay for it with a cancer. This ratio decreases with age but is still about 1 in 300 if the screening is done at the age of 50 years [34].

Conclusions

The dictum says that the fact that something can be done does not necessarily mean that it should be done. Multislice CT angiography provides colourful and relief pictures of the coronary tree. A true stenosis is detected most (but not all) of the times but artefacts are abundant. Just screening for calcium will raise rather than soothe unwarranted worries. Doing a full CT angiogram will only acquit a patient older than 50 years from the suspicion of having coronary artery disease if the interpreter is experienced and bold enough to take the many artefacts on his account. Less experienced operators (particularly radiologists

Table 2
Comparison of CT and conventional coronary angiography.

	multislice CT coronary angiography	conventional coronary angiography
Price of equipment	2–3 Mio (CHF)	2–3 Mio (CHF)
Personnel required	1 physician, 1 radiology assistant	1 physician, 1–2 nurses/technicians
Time per procedure	30 minutes	30 minutes
Technical failures	30% (patient compliance, heart rate, calcifications)	0%
Resolution	0.33 mm × 0.2 s, second order branches [18, 29, 30]	0.05 mm × 0.02 s, third order branches
Pressure measurements	–	+
Flow velocity measurements	–	+
Quantification of collaterals	(+)	+
Matching of stenosis with wall motion	(+)	+
Ad hoc therapy (1-stop-shop)	–	+

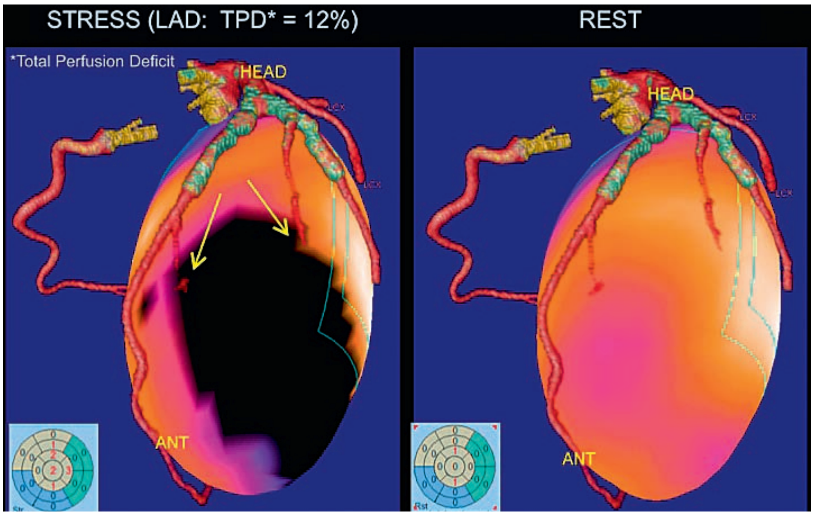

Figure 4
Integrated 64-slice CT-angiography and SPECT-imaging. The left picture indicated the myocardial perfusion deficit of the diseased (stop of flow) diagonal and marginal branches (arrows) which provides additional information to the purely anatomical picture at the right which shows that the proximal stents are patent. (With courtesy: Syntermed Software and C.A. Santana, MD, Emory University, Atlanta, GA, USA.)

not privy to the patient's history and global situation) may be unwilling to take the responsibility of parting with a clean bill of health in light of the artefacts and vessels that they cannot really see. The indication for coronary angiography is the consequence even in patients who basically dropped in from the street to have a check-up and would not have wound up with coronary angiography if they had done a conventional exercise test after a thorough history and physical examination in a cardiologist's office. Those who have true disease are likely to be properly detected and consequently sent for angiography. If only they had not already spent their yearly allowance of x-ray exposure before getting to the one-stop-shop they should have stopped by in the first place. MR coronary angiography is lagging behind in resolution but we have to wait for it, to find a proper tool for mass screening for coronary artery disease.

What remains for CT is the diagnosis of large structures such as valves, congenital anomalies, and perhaps the distinction between extremes in coronary artery disease. In the work-up of dilated cardiomyopathy, for instance, coronary artery disease is either advanced (postmyocardial infarction heart failure) or non existent (idiopathic heart failure). Maybe there, a possible playground opens up for CT coronary angiography despite its poor accuracy and prohibitive radiation dose [19]. And then again, maybe not.

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