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Cardiac CT angiography: technical aspects in 2012

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With the advent of the multidetector computed tomography (CT), cardiac computed tomography angiography (CCTA) has become a viable non-invasive method to rule out obstructive coronary artery diseases (CAD) due to its excellent negative predictive value. CCTA is mainly indicated in those patients presenting with clinically low-to-intermediate pretest likelihood for CAD.

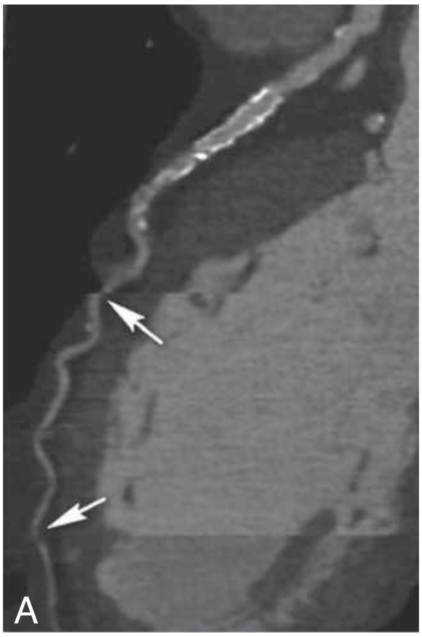
Despite its high diagnostic accuracy for detection of obstructive coronary artery disease, insufficient temporal, spatial or contrast resolution may sometimes provide incomplete or even misleading images of some coronary segments. These image artifacts are the main cause for misinterpretation regarding the presence of CAD and the successful use of CCTA depends on operator awareness of these potential pitfalls.

CCTA image quality determinants and artifacts

CCTA is technically complex and subject to constraints that may result in image artifacts. Key factors determining CCTA image quality include temporal resolution, spatial resolution, contrast resolution and noise.

Artifacts that may reduce image quality include blurring (Fig. 1), stairstep (Fig. 2) and blooming artifacts, low attenuating, streak, windmill or rod artifacts, vessel tracking artifacts, the omission of the region of interest, pseudostenosis and non-depiction of one or several coronary artery segments.

Insufficient tissue-contrast, limited spatial and temporal resolution, and radiation dose have until now prevented



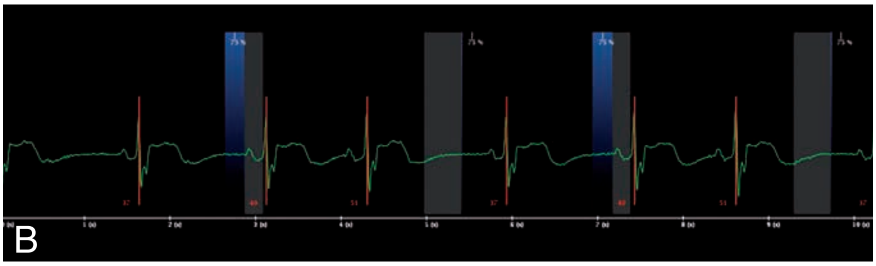
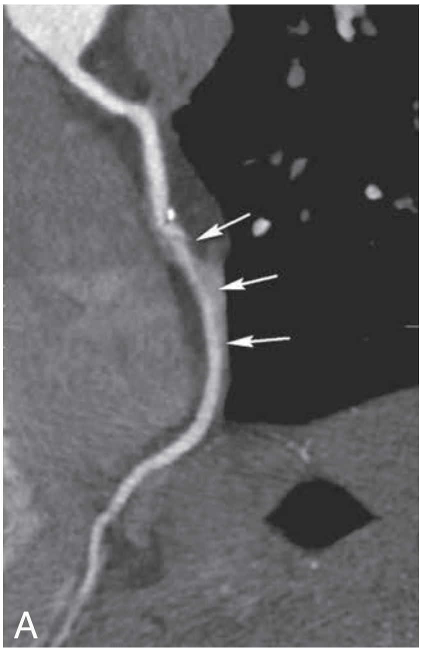


Fig. 2. — Stairstep artifacts of the left anterior descending artery (arrows in A) due to cardiac arrhythmia (HR between 37 and 51 beats per minute in B) in this prospective ECG-triggered acquisition.



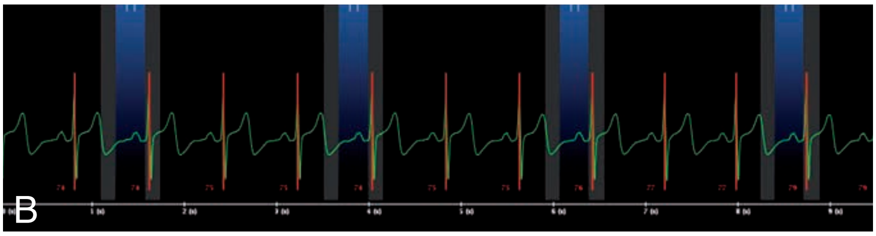


Fig. 1. — Cardiac motion-related blurring artifact of the second segment of the right coronary artery (arrows in A) due to high heart rate (average heart rate of 75 beats per minute in B) in this prospective ECG-triggered acquisition.

CCTA being widely used in other clinical applications such as myocardial function or dynamic perfusion.

Recent advance

The rate of CCTA failure has substantially diminished as a result of recent vendor-specific technological advances in temporal, spatial and contrast resolution, noise reduction and arrhythmia detection. Due to these improvements, and despite radiation dose concerns, CCTA may yet become the one-shot-stop examination for both coronary artery disease and advanced applications such as perfusion assessment. Obviously this prospect warrants further clinical investigation.

Bibliography

1. Budoff M.J., Dowe D., Jollis J.G., Gitter M., Sutherland J., Halamert E., Scherer M., Bellinger R., Martin A., Benton R., Delago A., Min J.K.: Diagnostic performance of 64-multi-

detector row coronary computed tomographic angiography for evaluation of coronary artery stenosis in individuals without known coronary artery disease: results from the prospective multicenter ACCURACY (Assessment by Coronary Computed Tomographic Angiography of Individuals Undergoing Invasive Coronary Angiography) trial. *J Am Coll Cardiol*, 2008, 52: 1724-1732.
2. Vanhoenacker P.K., Heijenbrok-Kal M.H., Van Heste R., Decramer I., Van Hoe L.R., Wijns W., Hunink M.G.: Diagnostic performance of multidetector CT angiography for assessment of coronary artery disease: meta-analysis. *Radiology*, 2007, 244: 419-428.
3. Kroft L.J., de Roos A., Geleijns J.: Artifacts in ECG-synchronized MDCT coronary angiography. *AJR*, 2007, 189: 581-591.
4. Choi H.S., Choi B.W., Choe K.O., Choi D., Yoo K.J., Kim M.I., Kim J.: Pitfalls, artifacts, and remedies in multi- detector row CT coronary angiography. *Radiographics*, 2004, 24: 787-800.
5. Nicol E.D., Arcuri N., Rubens M.B., Padley S.P.: Considerations when introducing a new cardiac MDCT service. Avoiding the pitfalls. *Clin Radiol*, 2008, 63: 355-369.
6. Nakanishi T., Kayashima Y., Inoue R., Sumii K., Gomyo Y.: Pitfalls in 16-detector row CT of the coronary arteries. *Radiographics*, 2005, 25: 425-438.
7. Mahesh M., Cody D.D.: Physics of cardiac imaging with multiple-row detector CT. *Radiographics*. 2007;27: 1495-1509.

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Imaging of the aortic root and ascending aorta

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Introduction

In recent years there has been increasing interest in the non-invasive imaging of the aortic root and ascending aorta. This is in part due to the exploration of the capabilities of CT-imaging in the assessment of the aortic valve, including the evaluation of aortic valve stenosis and insufficiency. Recent advances in transcatheter valve implantation techniques targeted at the aortic valve have also spurred interest in the non-invasive evaluation of the complex anatomy of the aortic root.

Finally, the ascending aorta is a sometimes underestimated source of acute chest pain.

Aortic valve and root

While the aortic valve has traditionally three cusps (Fig. 1), many variations can exist. Up to 1-2% of the population has a bicuspid valve (Fig. 2). Its presence has potential important clinical consequences, as a bicuspid aortic valve is more susceptible to premature degeneration, and is associated with a varying degree of aortic valve dysfunction. Consequently, when a dilated ascending aorta is observed in a young adult, a bicuspid aortic valve has to be considered (Fig. 3). Secondary to wear and tear, a bicuspid valve can present with thickened and partially calcified cusps at a relatively young age. Nevertheless, the amount of calcification by itself cannot be adequately used as a predictive marker for valve dysfunction (Fig. 3). Finally, a bicuspid valve can be associated with other congenital anomalies, including an aortic coarcatio.

A morphologically normal aortic root incorporates three sinuses of Valsalva of equal size and a tricuspid valve. In analogy with the variation in numbers of cusps, significant discrepancy in the development of these sinuses and cusps can exist (Fig. 4). As such, an aortic valve with a hypoplastic cusp and associated smaller sinus can consequently mimick a 'true' bicuspid valve (Fig. 5). CT has proven to be an excellent tool in the evaluation of valve morphology, often acting complimentary to the echocardiography-derived evaluation. While magnetic resonance (MR) imaging and echocardiography are traditionally the methods of choice in the evaluation of aortic valve dysfunction, several studies have demonstrated the ability of ECG-gated CT studies to correctly assess both aortic valve stenosis and regurgitation (Fig. 6). In contrast to the mentioned traditional imaging modalities, this evaluation requires an additional radiation exposure which can be substantial. Therefore, we do not recommend this in routine practice, its use better reserved for application on a case-by-case basis.

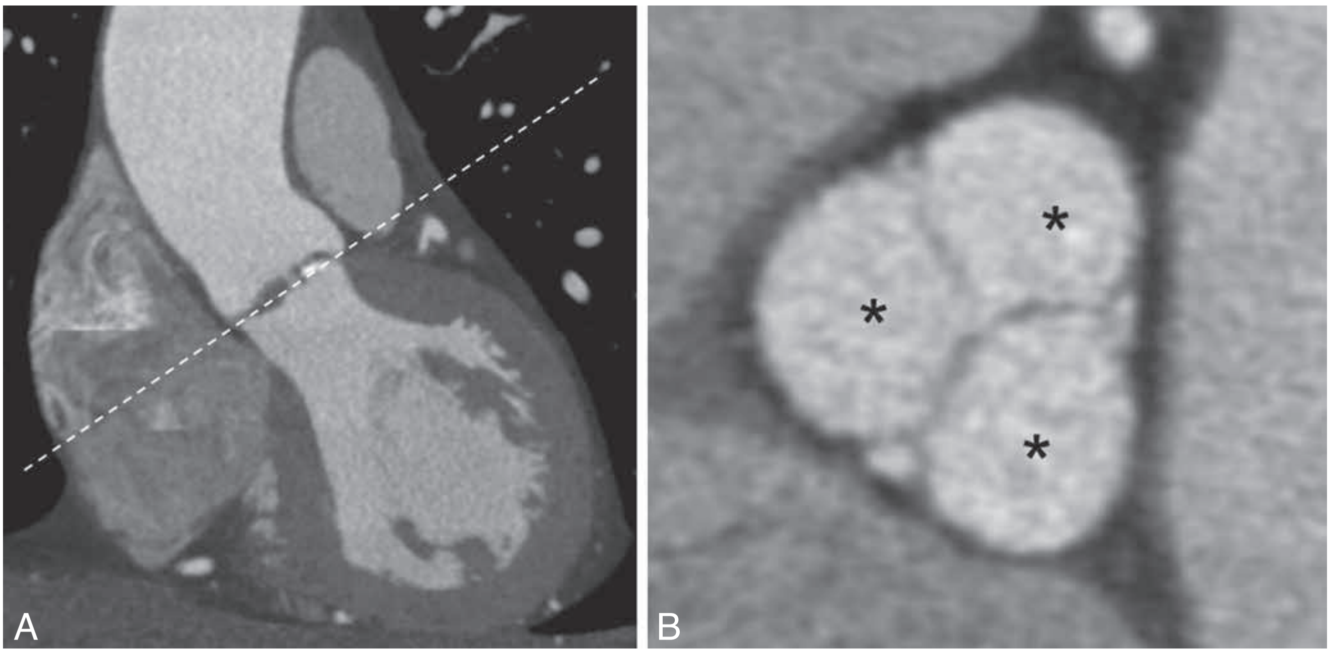

Fig. 1. – The aortic root has a double-oblique orientation, but a rough initial cross-sectional reformation can be obtained by aligning the imaging plane in an oblique fashion along the aortic valve cusps (dashed line) on a coronal reformatted image (A). The aortic root has three sinuses of Valsalva (asterisk in B), and contains a normally tricuspid aortic valve.

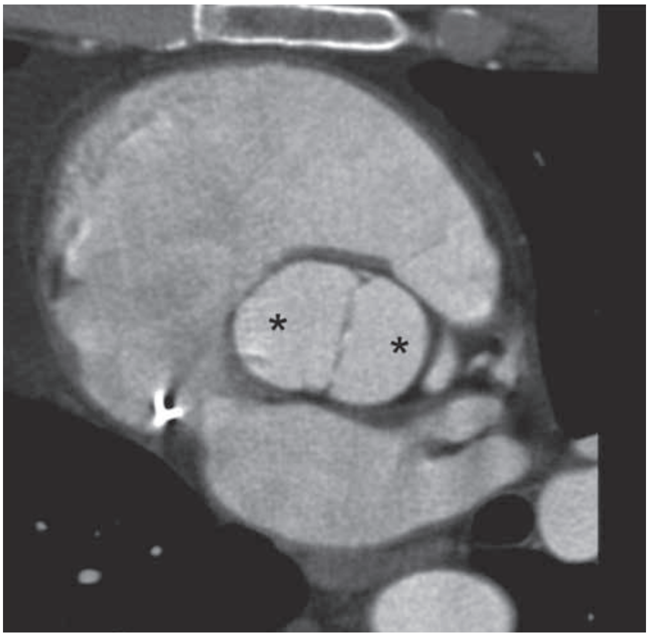

Fig. 2. – Double-oblique reformatted cross-sectional contrast-enhanced CT image in a 42-year-old man demonstrating the typical appearance of a bicuspid aortic valve. Note that there are only two sinuses of Valsalva (asterisk).

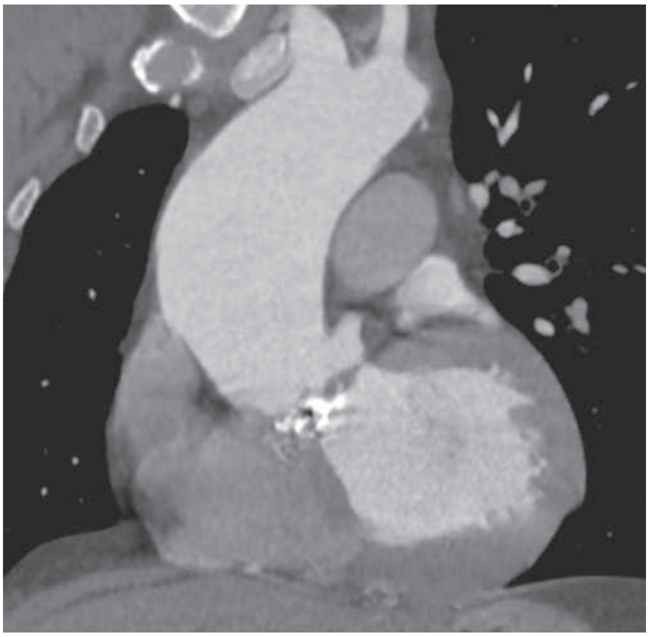

Fig. 3. – Coronal contrast-enhanced CT image demonstrating a premature degenerated bicuspid valve in a 36-year-old woman with extensive valve calcifications and thickened cusps. Note the dilated ascending aorta, a common associated finding secondary to the hemodynamic effects of aortic valve dysfunction.

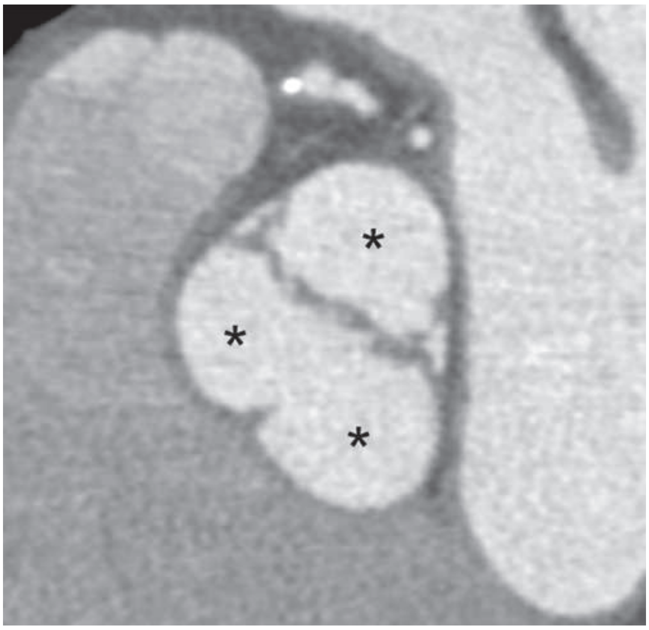

Fig. 4. – A 52-year-old man with an acquired functionally bicuspid valve. The cross-sectional reformatted contrast-enhanced CT image reveals three sinuses of Valsalva (asterisk), but only two cusps. This functionally bicuspid appearance can be the end result of fusion between two cusps, in this case secondary to a decade-old valve infection. As such, originally tricuspid aortic valves can become functionally bicuspid.

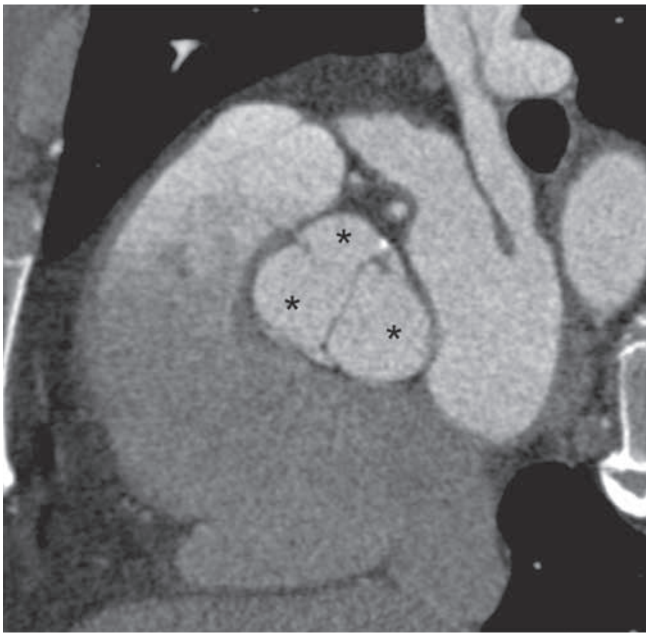

Fig. 5. – A 65-year-old man with a hypoplastic left coronary cusp on a cross-sectional contrast-enhanced CT image through the aortic valve. The hypoplastic left coronary cusp and left sinus of Valsalva make this valve appear almost bicuspid. Many variations exist in the morphology of the aortic valve. While CT can deliver excellent image quality, the associated radiation exposure and the lack of true functional information makes it not suitable for routine valve evaluation. Consequently, the application of CT for the evaluation of valve morphology must be restricted on a case-by-case basis, and always in conjunction with the findings of echocardiography and magnetic resonance imaging.

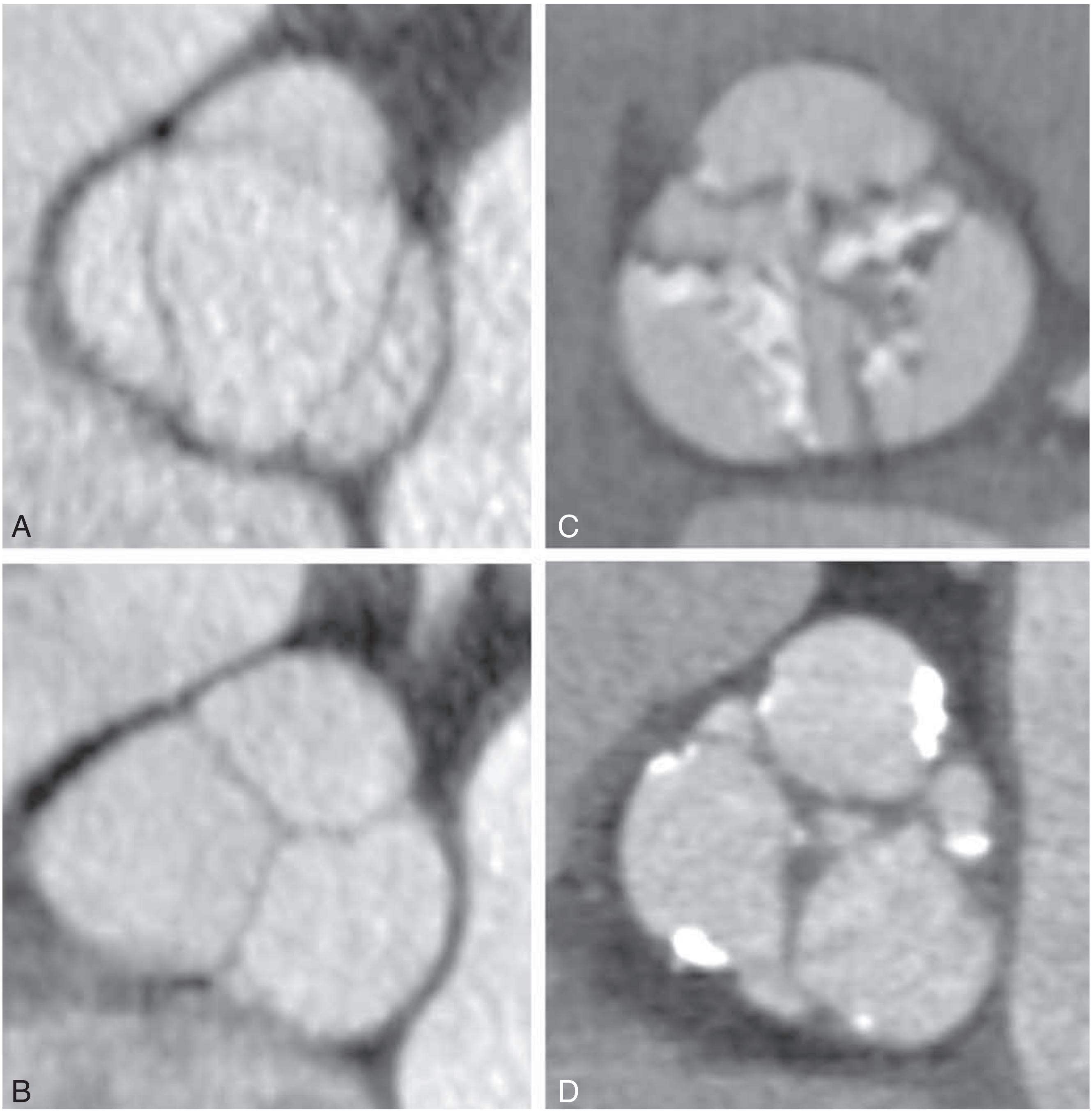

Fig. 6. – Evaluation of aortic valve stenosis and insufficiency using CT. Panel A illustrates the normal opening of the valve during systole. Panel B conversely demonstrates the only slight systolic valve opening in an 82-year-old man with critical aortic valve stenosis. Panel C shows the normal closing of the aortic valve in the end-diastolic phase of the cardiac cycle. Panel D reveals in the same cardiac phase a residual opening corresponding with aortic valve insufficiency. Functional aortic valve evaluation is traditionally reserved for echocardiography and magnetic resonance imaging. CT is, despite its excellent planimetric capabilities, not routinely indicated herefore.

Pre-operative evaluation of the aortic annulus

With the development of transcatheter valve implantation techniques for treatment of critical aortic valve stenosis, considerable attention is currently given to the optimal pre-procedural evaluation of the aortic annulus dimensions using non-invasive techniques. While echocardiography, most notable transesophageal ultrasound, has been successfully used in different trials for the evaluation of annular dimensions, it is now widely recognized that the excellent three-dimensional capabilities of CT can make a significant contribution in optimizing annular sizing. Several CT-based studies of the annular dimensions have indicated an oval annular morphology in a majority of cases, in contrast to the circular contour which was always assumed using two-dimensional techniques like echocardiography. Current research concentrates, among others, in establishing the optimal integration of different imaging tools for achieving optimal transcatheter valve size selection for a given patient, and to subsequently prevent or minimize paravalvular regurgitation.

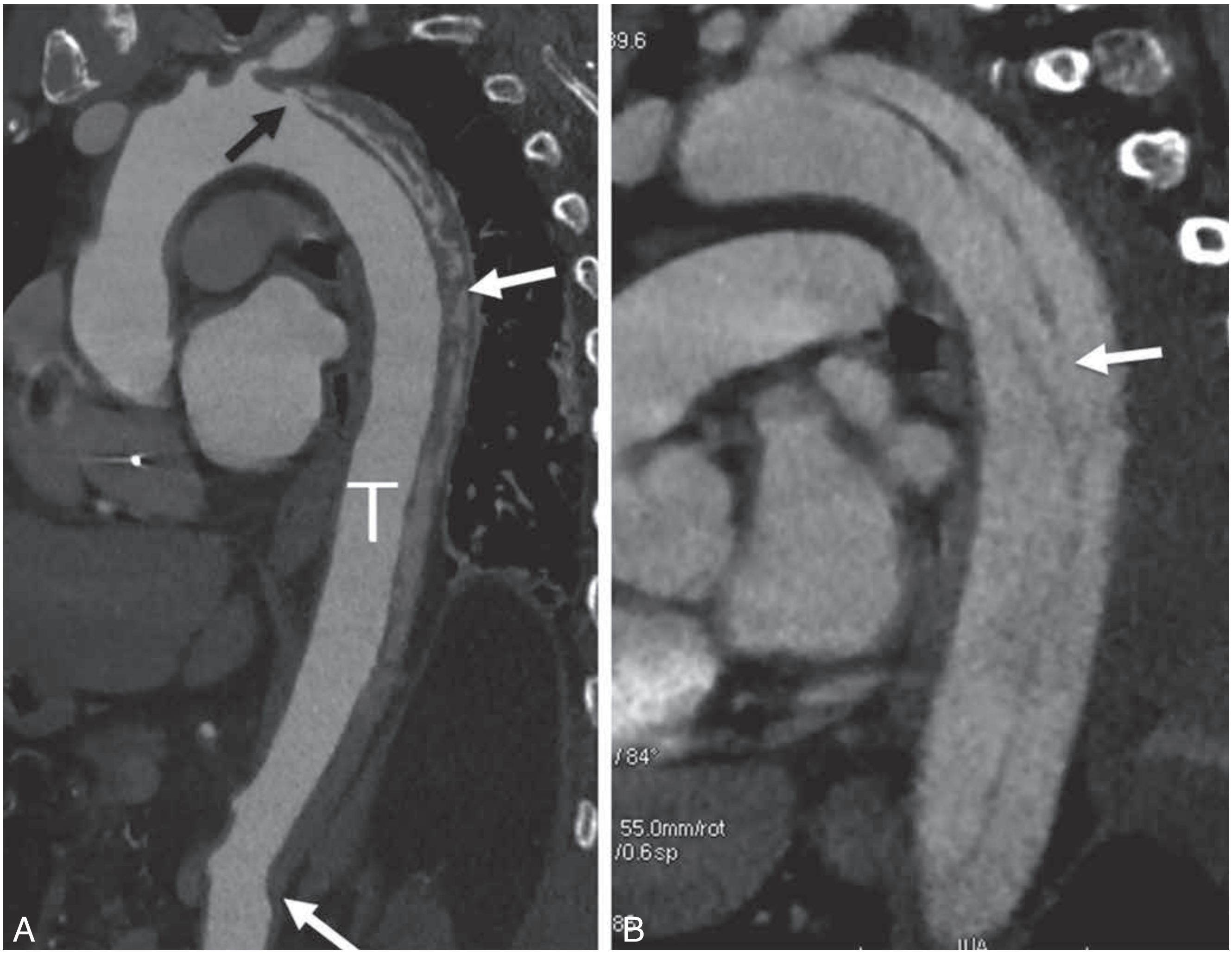

Fig. 7. – Evolution from an intramural hematoma to a classic dissection in a 32-year-old man with acute chest pain. On admission, the sagittal contrast-enhanced CT image (A) reveals a clear intramural hematoma (white arrows), with a small entry site (black arrow) just distally from the left subclavian artery, and no clear re-entry site. This image shows the clear distinction between one channel of flowing blood (large true lumen T), and one channel of stationary blood (intramural hematoma). However, after 6 days a new CT examination now shows several entry- and re-entry sites with two channels of flowing blood and a consequently larger false lumen. This changed appearance now represents a classic form of (in this case type-B) aortic dissection, and illustrates the varying morphology of the acute aortic syndrome.

Acute aortic syndrome

The term 'acute aortic syndrome' is used to indicate the trilogy of acute aortic dissection, intramural hematoma and penetrating atherosclerotic ulceration as aortic-based causes of acute chest pain. However, contemporary criticism points out that the distinction between these three causes is conceptually flawed, as especially acute aortic dissection and intramural hematoma most probably represent two separate presentations of the same clinical entity. Most important, it is now preferred to use 'intramural hematoma' as a descriptive term, indicating stationary blood within the aortic wall. This stationary blood is formed as blood from the main (true) lumen enters the aortic wall through a small and often on CT or MR imaging unnoticeable defect in the intima layer. As is often the case, there is only an entry site in the aortic wall, and no detectable re-entry site. Consequently, this stationary blood forms a thrombus in the aortic wall, with a 'false' lumen that is typically semicircumferential and smaller than the main true lumen.

It is furthermore important to recognize that this situation can evolve to a classic aortic dissection. This can occur when one or several re-entry sites develop along the course of the diseased aortic wall (Fig. 7). On such occasion, there is transition to two channels of flowing blood, with often the false lumen having a larger cross-sectional diameter than the true lumen.

Bibliography

1. Ueda T., Chin A., Petrovitch I., et al.: A pictorial review of acute aortic syndrome: discriminating and overlapping features as revealed by ECG-gated multidetector-row CT angiography. *Insights Imaging*, 2012, 3: 561-571.
2. Goffinet C., Kersten V., Pouleur A.C., et al.: Comprehensive assessment of the severity and mechanism of aortic regurgitation using multidetector CT and MR. *Eur Radiol*, 2010, 20: 326-336
3. Feuchtner G.M., Müller S., Bonatti J., et al.: Sixty-four slice CT evaluation of aortic stenosis using planimetry of the aortic valve area. *Am J Roentgenol*, 2007, 189: 197-220.
4. Lehmkuhl L., Foldyna B., Von Aspern K., et al.: Inter-individual variance and cardiac cycle dependency of aortic root dimensions and shape as assessed by ECG-gated multi-slice computed tomography in patients with severe aortic stenosis prior to transcatheter aortic valve implantation: is

it crucial for correct sizing? *Int J Cardiovasc Imaging*, 2013, 3: 693-703.
5. Achenbach S., Delgado V., Hausleiter J., et al.: SCCT expert consensus document on computed tomography imaging before transcatheter aortic valve implantation (TAVI)/transcatheter aortic valve replacement (TAVR). *J Cardiovasc Comput Tomogr*, 2012, 6: 366-380.

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Non-coronary applications of cardiac CT (with MR correlation)

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The high diagnostic accuracy and high negative predictive value of cardiac multidetector row computed tomography (MDCT) to evaluate coronary artery stenoses is very well known, and as such, this technique has been put forth as the most promising non-invasive exam. Additionally, the full volumetric dataset allows for analysis of a wide range of other cardiac pathologies.

Left ventricular volumes and systolic function can be accurately assessed, if both systolic and diastolic frames are acquired. The same holds true for evaluation of (artificial) cardiac valves. Furthermore, accurate high-resolution visualization of the atria, pulmonary veins and the cardiac venous system is often sought by the cardiologist performing electrophysiological procedures.

The newest technological advances allow these exams to be performed at relatively low radiation doses. This brings novel applications such as stress-perfusion imaging and cardiac dual energy imaging into the picture and opens the door towards CT imaging of myocardial infarction and ischemia.

Cardiac function assessment

Assessment of global systolic function can be achieved by reconstructing a 4D retrospective gated spiral acquisition in different phases throughout the cardiac cycle (typically a phase every 10% of the RR interval) to identify end-diastolic and end-systolic phases. By delineating the endocardial surface and by using the Simpson method, the LV volumes are obtained. The accuracy of MDCT-derived functional parameters has been extensively investigated and compared with other imaging modalities such as gated single-photon emission computed tomography (SPECT) and magnetic resonance imaging (MRI) and has been found to be both a very reproducible and accurate means to quantify LV volumes and LV ejection fraction.

In recent years however, the habit of obtaining retrospectively gated scans has strongly declined, since newer acquisition algorithms such as the ‘step and shoot’ prospective gating method and the emergence of single heartbeat acquisitions have allowed for a dramatic decrease in radiation dose, but these schemes only acquire information about the second part of the cardiac cycle, thus disallowing any functional evaluation. A motivated choice has to be made by the radiologist, based on the clinical history and depending on what information is to be gained, whether to choose for a low-dose scan or a full functional 4D evaluation.

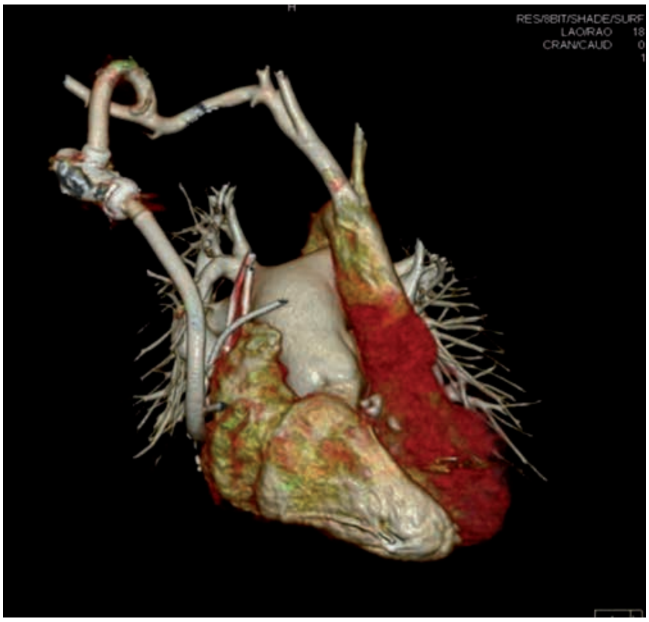

Fig. 1. — Circulite left ventricular assist device. 3D VRT reconstruction of the in- and outflow canullae.

Imaging of cardiac valves

Homologous to the situation described for cardiac function, the high spatial resolution allows for detailed analysis of the cardiac valves. Cardiac CT provides important information on the presence of (peri)valvular and annular calcifications, variations in the number of valve leaflets, and recently more specifically on the aortic valve anatomy, geometry, and valve area in patients considered for transarterial aortic valve implantation (TAVI) (Fig. 1).

In selected cases, imaging of artificial valves and assist devices can be considered, since the new fast acquisition algorithms and artifact-reducing reconstruction kernels allow accurate anatomical and functional visualization in case of valve dysfunction.

The exact value of valvular assessment by cardiac CT is largely still under investigation, re-emphasized by its grading in the recent Appropriateness Criteria for Cardiac Computed Tomography and Cardiac Magnetic Resonance Imaging, from the American College of Cardiology, as an ‘uncertain indication’ (Fig. 2).

Imaging of the atria and the cardiac venous system

In patients with drug-resistant atrial fibrillation, transcatheter radiofrequent ablation can be used to thermally destroy atrial foci suspect for initiation of these arrhythmias. These procedures are often aided by cardiac CT by identifying the exact pulmonary vein anatomy, of which there are many variants (large or small venoatrial junctions, common ostia or accessory pulmonary veins).

In end-stage heart failure, cardiac resynchronization therapy (CRT) has been shown to increase survival and provide systematic relief of symptoms. This procedure requires positioning of a pacing lead near the inferolateral wall of the LV. The main factor determining the success of a transvenous LV lead implantation is cardiac anatomy, particularly of the coronary venous system, which is known to be highly variable. With only a small adaptation of the regular cardiac scanning algorithm, many studies have shown reliable visualization of the cardiac venous anatomy and accurate quantification on the dimensions of the ostium of the coronary sinus and the diameter of the target veins.

Imaging of myocardial infarction and ischemia

Similar to what is more commonly performed in an MRI setting, cardiac CT can be are acquired during the first pass of a bolus of contrast agent, theoretically allowing hypoperfused areas within the myocardium regions to appear with low attenuation.

Although currently perfusion CT is still largely investigational and still under development in preclinical animal models, a good accuracy to detect myocardial infarction has been observed. In similar studies, delayed phase scanning showed delayed hyperenhancement in the infarct area.

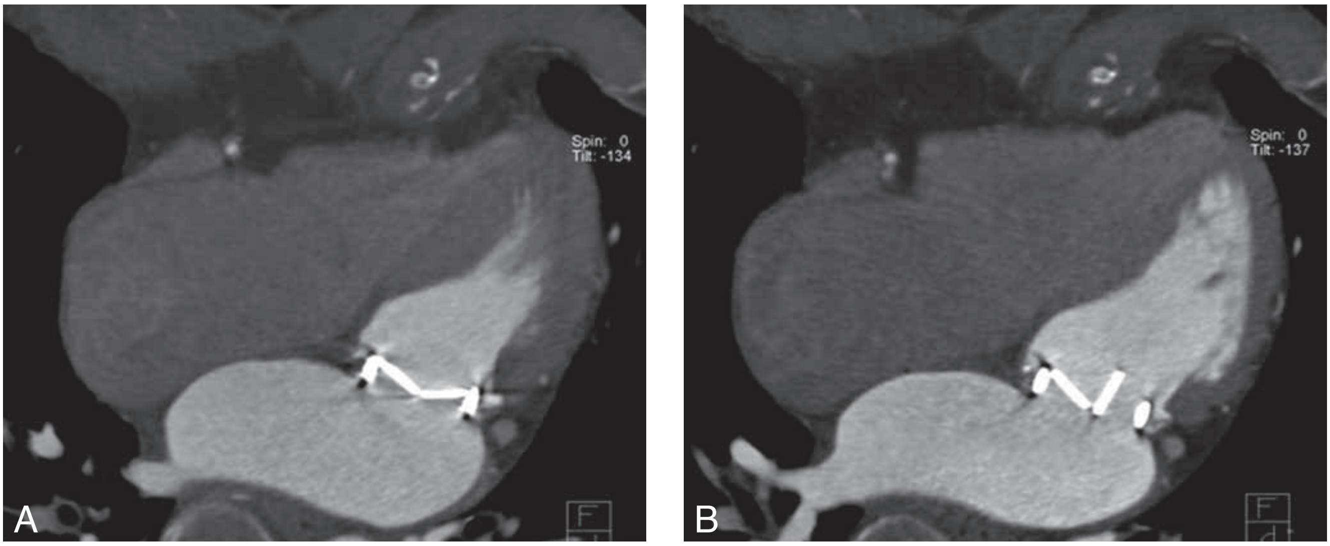

Fig. 2. — Systolic (A) and diastolic (B) image of an artificial mitral valve that shows absence of proper opening of the posterior leaflet.

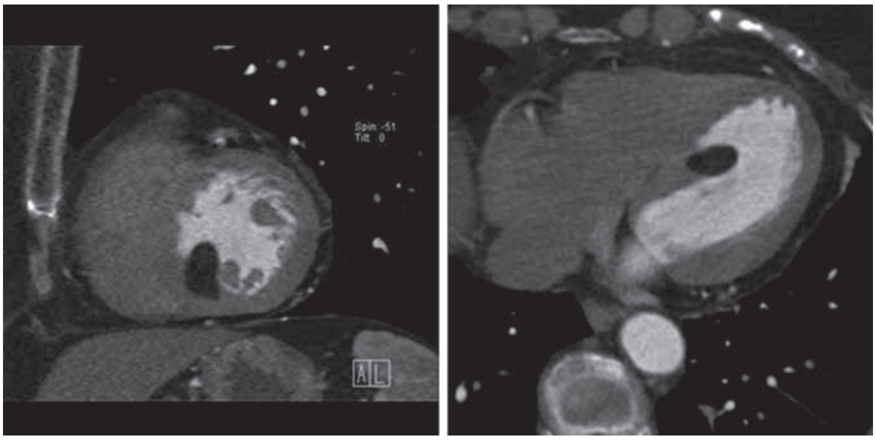

Fig. 3. — Short-axis (left) and transverse (right) CT image of a cardiac lipoma, arising from the inferobasal interventricular septum.

A significant coronary stenosis will usually not show any signs of decreased perfusion in a resting state. Therefore, also the feasibility of performing adenosine or dipyridamole stress myocardial perfusion imaging has been explored and has shown potential to provide information on stress-induced ischemia in selected patients. Issues of patient safety, unfamiliarity with monitoring requirements and difficulties in acquiring reliable data in patients with drug induced tachycardia during CT have so far limited its wide spread use in clinical practice.

Imaging of myocardial masses and pericardial diseases

A cardiac mass can often be detected as an incidental finds on cardiac CT performed for other indications. The majority of these lesions are cardiac thrombi, usually located in the left atrium or left atrial appendage in patients with history of atrial fibrillation and adjacent to areas of infarction tissue in patients with ischemic heart disease. These thrombi appear as non-attenuating mural masses, usually in high contrast to the iodine within the cardiac chambers. Other masses, such as primary and secondary tumors, or mimics of normal anatomy, may be readily detected by CT, but may prove to be difficult to characterize (Fig. 3). In these cases MRI is the preferred imaging modality since its multiparametric approach allows for more accurate tissue characterization.

Pericardial diseases, expressed as focal or generalized thickening, contrast enhancement in inflammatory conditions and calcifications in more chronic settings are easy to investigate with cardiac CT, especially in scenarios where echocardiography is known to underperform, e.g. poor acoustic window due to constitution or in the immediate postoperative setting. Nevertheless, the influence of pericardial disease on diastolic function, or the functional significance of pericardial thickening are rarely assessable by CT, where this is rather comfortably done in echocardiography and cardiac MRI.

Conclusions

Cardiac CT can be considered as a valuable non-invasive imaging modality for the study of different non-coronary cardiac diseases. The ability to perform high quality functional analyses of ventricular and valvular function has been extensively proven, but must be looked at skeptically, since this comes at a significant cost in terms or radiation dose.

Cardiac CT is also being increasingly solicited as the preferred modality for planning of different minimally invasive procedures, such as transcatheter ablation of arythmogenic foci within the atria or TAVI and CRT implantations.

The use of CT for investigation of myocardial scar formation and ischemia visualization is still in its investigational phase.

Bibliography

1. Nasis A., Mottram P.M., Cameron J.D., Seneviratne S.K.: Current and Evolving Clinical Applications of Multidetector Cardiac CT in Assessment of Structural Heart Disease. *Radiology*, 2013, 267: 11-25.
2. Hendel R.C., Patel M.R., Kramer C.M., et al.: ACCF/ACR/SCCT/SCMR/ASNC/NASCI/SCAI/SIR 2006 appropriateness criteria for cardiac computed tomography and cardiac magnetic resonance imaging: a report of the American College of Cardiology Foundation Quality Strategic Directions Committee Appropriateness Criteria Working Group, American College of Radiology, Society of Cardiovascular Computed Tomography,

Society for Cardiovascular Magnetic Resonance, American Society of Nuclear Cardiology, North American Society for Cardiac Imaging, Society for Cardiovascular Angiography and Interventions, and Society of Interventional Radiology. *J Am Coll Cardiol* 2006;48:1475–1497.
3. Hurlock G.S., Higashino H., Mochizuki T.: History of cardiac computed tomography: single to 320-detector row multislice computed tomography. *Int J Cardiovasc Imaging*. 2009;25 Suppl 1:31-42.
4. Tops L.F., Krishnàn S.C., Schuijf J.D., Schalij M.J., Bax J.J.: Noncoronary Applications of Cardiac Multidetector Row Computed Tomography. *JACC Cardiovasc Imaging*, 2008, 1: 94-106
5. Schuleri K.H., George R.T., Lardo A.C.: Applications of cardiac multidetector CT beyond coronary angiography. *Nat Rev Cardiol*, 2009, 6: 699-710.
6. Rodríguez-Granillo G.A., Ingino C.A., Lylyk P.: Myocardial perfusion imaging and infarct characterization using multidetector cardiac computed tomography. *World J Cardiol*, 2010, 2: 198-204.
7. Leipsic J., Gurvitch R., Labounty T.M., Min J.K., Wood D., Johnson M., Ajlan A.M., Wijesinghe N., Webb J.G.: Multidetector computed tomography in transcatheter aortic valve implantation. *JACC Cardiovasc Imaging*, 2011, 4: 416-429.
8. Jongbloed M.R., Lamb H.J., Bax J.J., et al.: Noninvasive visualization of the cardiac venous system using multislice computed tomography. *J Am Coll Cardiol*, 2005, 45: 749-753.
9. Wang Z.J., Reddy G.P., Gotway M.B., Yeh B.M., Hetts S.W., Higgins C.B.: CT and MR imaging of pericardial disease. *Radiographics*, 2003, 23: S167-180.

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Acute chest pain and CT: current insights & cost-effectiveness

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Acute chest pain (ACP) is a common reason of admission at the emergency departments (ED), not infrequently representing a source of challenging dilemmas for clinicians and anxiety for patients with relevant legal implications related to inappropriate therapeutic management (1).

The list of differential diagnosis of ACP is extensive and ranges from benign musculoskeletal disorders to life-threatening conditions requiring immediate treatment such as acute coronary syndrome, aortic dissection, rupture of the esophagus, perforating peptic ulcer, pulmonary embolism and tension pneumothorax.

Current diagnostic algorithms may reliably rule out serious disorders in most of the cases however there is still persistence of an unacceptable rate of about 4-8% of patients with myocardial infarction or acute coronary syndrome who are inappropriately discharged from the ED due to the presence of normal initial cardiac enzyme levels associated with non-diagnostic/non-specific electrocardiographic (ECG) and echocardiographic alterations (2).

Furthermore, the growing pressure of legal disputes for malpractice and the reasonable clinical caution in excluding potentially lethal syndrome is a common cause of unnecessary diagnostic procedures and precautionary prolonged hospitalization with obvious economical implications.

Although an acute coronary syndrome is ultimately diagnosed in only 10 to 15% of patients who present with ACP, it has been estimated that the mean length of hospitalization is 4.6 days, with an average cost of approximately $23,000 per patient in the US an annual cost over $3 billion (3).

Primary objectives of social health systems in Europe and US are to speed-up diagnostic algorhythm, improve diagnostic accuracy and, obviously, reduce management costs.

In this clinical setting, contrast-enhanced coronary computed tomographic angiography (CCTA) has emerged as a promising non-invasive diagnostic tool, with an high sensitivity and specificity and a ~100% negative predictive for the exclusion of coronary artery disease, potentially allowing to improve clinical care of those patients.

A role of CCTA in supporting the triage of patients with suspected acute coronary syndrome has been hypothesized since early 2000' (4) and its impact on costs and health care has been subject of an extensive recent literature, nevertheless unanimous consensus was not achieved.

In particular, great emphasis was given to the so-called "triple rule out" protocol that offers in one-stop-shop exam a complete evaluation of thoracic cardiovascular structure, revealing three severe acute potentially lethal disorders (ischemic heart disease, acute aortic disease or pulmonary embolism).

Present article will discuss different acquisition protocols, clinical results and economical implications of CCTA in the clinical setting of ACP.

Clinical indications

According to current American Heart Association (AHA) guidelines, appropriateness of CCTA in patients presenting with symptoms of ACP has been indicated as "uncertain" in both patients presenting with persistent ECG ST-segment elevation following exclusion of myocardial infarction or with ACP of uncertain cause (score 6 out of 9 for both indications) and inappropriate in presence of a definite diagnosis of myocardial infarction (5).

The Asian Society of Cardiovascular Imaging (ASCI) guidelines, categorized clinical appropriateness to the exam according to pre-test probability of disease. Use of CCTA was indicated as "uncertain" in presence of low pre-test probability and "appropriate" in patients with intermediate and high pre-test likelihood (evidence level 7 out of 9 for both) excluding subjects with ST-segment elevation and/or positive cardiac enzymes in which examination was considered inappropriate (6).

A similar consensus was recently reported by the Italian sub society of cardiac radiology in which use of CCTA in patients with non-assessable ECG and /or equivocal laboratory biomarkers was scored as class II clinical indication (i.e. diagnostic information of clinical relevance provided) in presence of ACP whereas the triple rule out protocol application was regarded as potentially useful but still investigational (7).

The "Triple Rule Out" Protocol

Ideal CCTA protocol should represent the best compromise between the need for a comprehensive and reliable evaluation of all thoracic cardiovascular structures at the lowest radiation dose possible.

Recent technological advances enable an accurate and detailed imaging of coronary arteries, thoracic aorta and pulmonary arteries in a single contrast-enhanced ECG-gated CT scan.

Although the examination is potentially feasible even on 16-slice CT scanner, it is recommended to use last generation machines (64-slice or greater) implemented by radiation dose reduction tools and dedicated cardiac post-processing software.

Use of a preliminary unenhanced prospectively ECG-gated acquisition covering the entire thoracic aorta might be helpful to provide information regarding distribution and amount of coronary artery calcium and to eventually detect hyperdense vascular rims reflecting intramural aortic hematoma at the cost, however, of an increased patient's exposure.

The choice to apply retrospective or prospective ECG-synchronization techniques is conditioned by the available technology and patient's heart rate, keeping in mind the general concept that the combination of a stable and sinus heart rhythm and a heart rate of less than 65-70 beats per minute (depending on the scanner generation) is mandatory to obtain adequate image quality.

Radiation doses of retrospectively gated 64-slice CT range between 7 to 14 mSv when dose modulation strategies are applied whereas in prospectively ECG-gated triggering, a significant effective dose reduction is realistically feasible with a dose of 5 to 7 mSv, less than that from nuclear myocardial perfusion imaging. Recently, a high pitch dual-spiral cardiothoracic comprehensive protocol using a last generation dual source CT scanner has been proposed in patients with undifferentiated acute chest pain, allowing to minimize patient's individual exposure to an average 3.8 mSv.

Heart-rate control can be achieved in most of the cases intravenously administering a short-acting beta-blocker (like

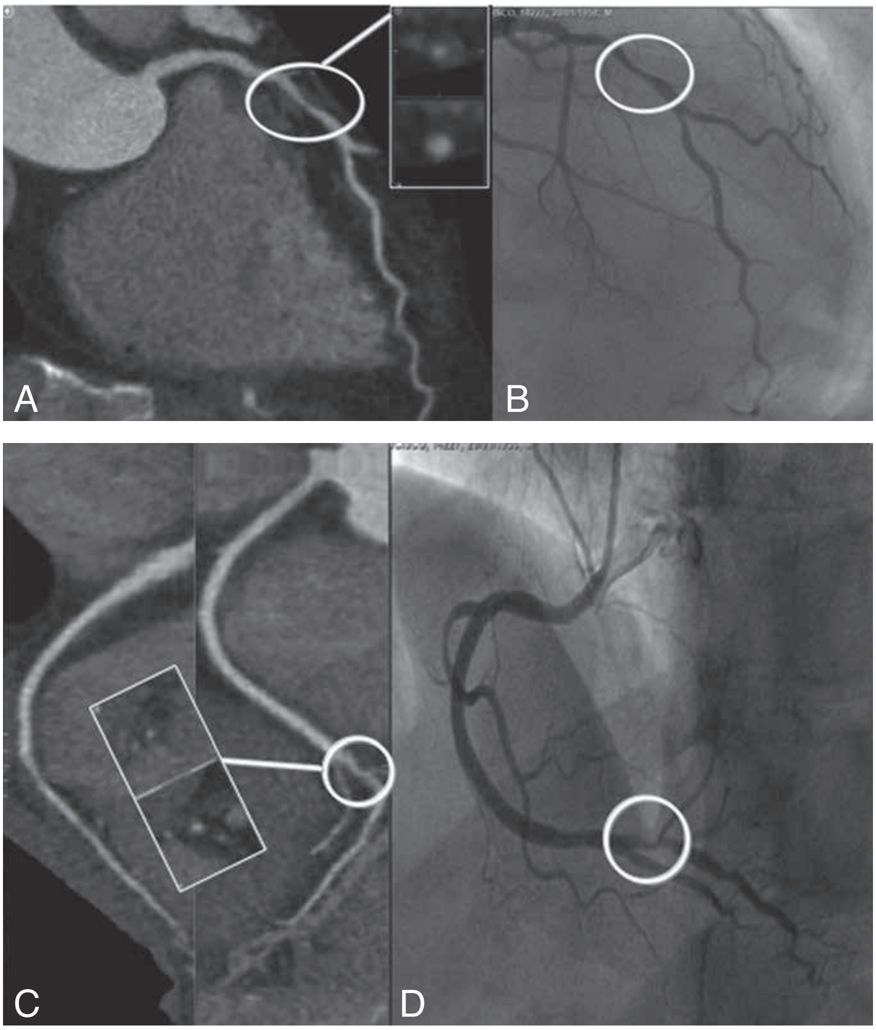

Fig. 1. — CCTA in a 63-year-old patient admitted at the ER due to recent atypical angina, presenting with negative ECG and enzymes. Curved planar reconstruction show the presence of an eccentric soft tissue lesion located in mid left anterior descending artery, causing moderate luminal stenosis (A). An high grade lesion is also located at the origin of left posterior descending artery (C) and was successfully treated with coronary stenting. Corresponding selective coronary angiography images are displayed in figures B and D.

metoprolol 5-20 mg or esmolol 10 mg/mL) few minutes prior to the examination excluding patients with general contraindications to the drug (asthma, sinus bradycardia and hypotension, atrioventricular block etc). Preliminary administration of sublingual nitroglycerin could also be useful to dilate coronary arteries.

Test bolus or bolus tracking protocol are strongly advisable to determine the optimal timing of contrast injection and when bolus tracking is selected we suggest to use a threshold of 120-140 HU and a region of interest placed within the ascending aorta. Contrast medium administration protocol should be adapted to the covered surface of body, however a bolus of 80–110 mL of contrast medium at a rate of 4-5.0 mL/s followed by a 40 mL saline flush is usually adequate to obtain an optimal vascular enhancement within the entire acquisition window.

Further technical aspects about the CT scan protocol are provided in a large expert consensus recently published (8).

Images interpretation

Radiological report of patients admitted with ACP should be promptly prepared and communicated to the referring clinical team of the ED in order to speed-up diagnostic workup; utilization of a pre-filled initial and final patient's report form has even been suggested on this regard (4).

A complete evaluation of both cardiac and non-cardiac structures needs to be provided, to rule out pulmonary embolism and aortic dissection and to exclude non-vascular causes of chest pain potentially affecting patient's management (eg. pneumotorax, pneumonia, pleural or pericardial effusion).

Coronary arteries evaluation should include detailed description of location, extent and morphological features of plaques, with particular attention to soft density lesions and to the so-called "napkin-ring sign" with is characterized by the presence of a ringlike attenuation pattern resembling the thin-cap fibroatheroma recognized as a precursor lesion for plaque rupture (9) (Fig. 1).

A strong prognostic value of CCTA was recently demonstrated, independent of traditional risk factors and calcium scoring, in a patient's cohort of 457 subject presenting with ACP in which the absence of plaques was associated with no clinical event in a follow-up period of 11 months (10).

Comprehensive cardiac evaluation should combine morphological information obtained from coronary arteries analysis with functional (ejection fraction, regional wall motion) and perfusional data, in order to correlate non-invasive angiographic findings with status of corresponding vascular territory (Fig. 2) (11).

Combined evaluation of regional wall motion abnormalities and myocardial perfusion defects has shown to improve detection of acute myocardial infarction with a sensitivity of 94% and specificity of 97%, using cardiac biomarkers and single photon emission CT (SPECT) myocardial perfusion imaging as reference standard (12).

Moreover, detection of regional myocardial perfusion defect has an additional diagnostic value to CCTA, reducing rates of false positive an improving the positive predicting value from 67% to 90.1%, if compared to rest sestamibi single-photon emission CT myocardial perfusion imaging (SPECT-MPI) (13).

Cost-effectiveness

Analysis of CCTA cost-effectiveness in the clinical setting of ACP has been a subject of interest in a large number of recently published papers, either based on simulated models of clinical and economic outcomes and on large patient's cohorts or metanalysis.

Main findings emerged from literature were the following:

1) Use of CCTA allows a higher rate of patient's discharge from ER with a shorter length of stay as compared to the standard of care (SOC) (14). Litt and colleagues (3) reported a remarkable 27% difference in the rate of early discharge of patients who underwent CCTA as compared to SOC with a significantly reduced median length of ER stay of 18.0 hours vs 24.8 hours. Similar results were found in a large metanalysis of four large trials reported reporting a significant reduction patient's stay, including both ED or total hospital stay (15).
2) The majority of authors found a cost saving ranging between 15% and 38% when use of CCTA was compared to

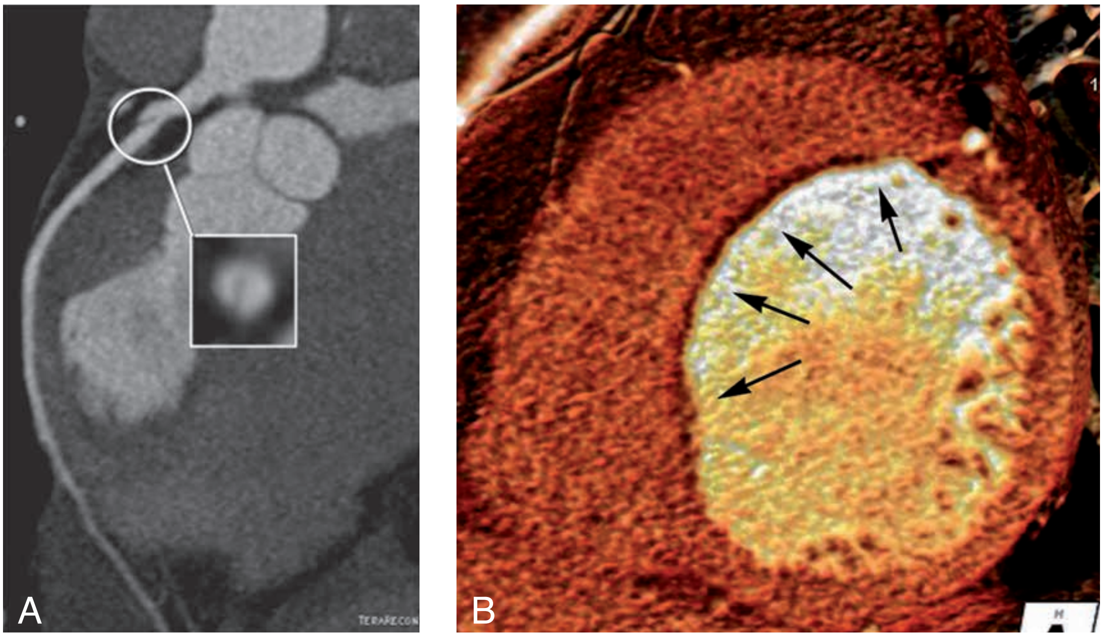

Fig. 2. — Left anterior descending artery post-traumatic focal dissection in a 26-year-old patient following a severe motorbike accident (A). Corresponding thin-slice volume rendering reconstruction shows the presence of a large perfusion defect located in the mid anterior-septal left ventricular wall perfectly matching distribution territory of the dissected vessel (B, arrows).

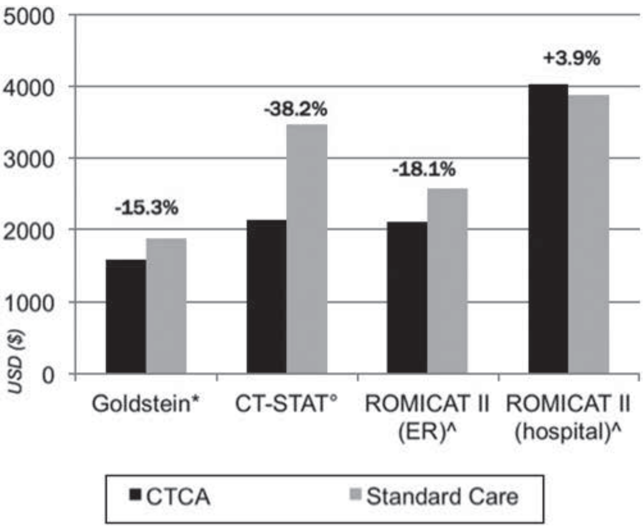

Fig. 3. — Bar chart showing analysis of CCTA cost effectiveness compared to standard of care. Data are plotted from reference #15 and derived from the metanalysis of 4 large clinical trials focused on patients with ACP. ROMICAT II study results are differentiated in discharged (ER only) vs hospitalized (hosp) patients.

SOC, mostly in patients with low- to intermediate-risk of disease (14-16) (Fig. 3).

3) CCTA allows higher detection of coronary arteries disease with subsequent increase of percutaneous and stenting procedures as emerged from the pooled data of a large study population 1,869 patients undergoing CCTA vs 1,397 undergoing SOC, with subsequent cost increase of 3.9% in case of hospitalization of CCTA patients (17). In positive CCTA patients, therefore, the increase of downstream testing and procedures may cause a cumulative mean cost of care similar to the SOC group.

Conclusions

The very high negative predictive value of CCTA for CAD minimizes risk of undetected acute coronary syndromes providing relevant impact on patient's prognosis and clinical management (3, 16).

CCTA in ACP is a fast, feasible, and robust imaging technique which is becoming widely available in the ER with an acceptable dose exposure when using last generation scanners combined with appropriate dose reduction strategy. It allows a rapid patient's discharge with significant health-care costs reduction and improved individual therapeutic management.

On the other hand, the presence of an high-grade stenosis does not necessarily reflect an acute coronary syndrome and non-invasive angiographic findings should be necessarily combined with complementary functional/perfusional tests to rule-out underlying myocardial ischemia due to the assumption that coronary physiology is the critical decision point for consideration of revascularization.

Additional limitations to widespread utilization of CCTA in this setting rely on the current limited availability of dedicated cardiac imaging specialist and on the still high number of false positive cases related to the presence of extensive vascular calcifications with intraluminal beam hardening artifacts.

The future is anyway probably going in the direction of CCTA as acknowledged by clinical guidelines and appropriateness criteria of the main national and international medical societies and witnessed by the extensive literature strongly supporting its utilization in large clinical trials.

References

1. Kolansky D.M.: Acute coronary syndromes: morbidity, mortality, and pharmacoeconomic burden. *Am J Managed Care*, 2009, 15: S36-41.
2. Hoffmann U., Pena A.J., Cury R.C., et al.: Cardiac CT in emergency department patients with acute chest pain. *Radiographics* : a review publication of the Radiological Society of North America, Inc 2006, 26: 963-78; discussion 979-980.
3. Litt H.I., Gatsonis C., Snyder B., et al.: CT angiography for safe discharge of patients with possible acute coronary syndromes. *New Engl J Med*, 2012, 366: 1393-1403.
4. White C., Read K., Kuo D.: Assessment of chest pain in the emergency room: what is the role of multidetector CT? *Eur J Radiol*, 2006, 57: 368-372.
5. Taylor A.J., Cerqueira M., Hodgson J.M., et al.: ACCF/SCCT/ACR/AHA/ASE/ASNC/NASCI/SCAI/SCMR 2010 appropriate use criteria for cardiac computed tomography. A report of the American College of Cardiology Foundation Appropriate Use Criteria Task Force, the Society of Cardiovascular Computed Tomography, the American College of Radiology, the American Heart Association, the American Society of Echocardiography, the American Society of Nuclear Cardiology, the North American Society for Cardiovascular Imaging, the Society for Cardiovascular Angiography and Interventions, and the Society for Cardiovascular Magnetic Resonance. *J Am Coll Cardiol*, 2010, 56: 1864-1894.
6. Asci C.C.T., Group C.M.R.G.W., Tsai I.C., et al.: ASCI 2010 appropriateness criteria for cardiac computed tomography: a report of the Asian Society of Cardiovascular Imaging Cardiac Computed Tomography and Cardiac Magnetic Resonance Imaging Guideline Working Group. *Int J Cardiovasc Imag*, 2010, 26 Suppl 1: 1-15.
7. di Cesare E., Carbone I., Carriero A., et al.: Clinical indications for cardiac computed tomography. From the Working Group of the Cardiac Radiology Section of the Italian Society of Medical Radiology (SIRM). *Radiologia Medica*, 2012, 117: 901-938.
8. American College of Cardiology Foundation Task Force on Expert Consensus D, Mark D.B., Berman D.S., et al.: ACCF/ACR/AHA/NASCI/SAIP/SCAI/SCCT 2010 expert consensus document on coronary computed tomographic angiography: a report of the American College of Cardiology Foundation Task Force on Expert Consensus Documents. *J AmColl Cardiol*, 2010, 55: 2663-2699.
9. Kashiwagi M., Tanaka A., Shimada K., et al.: Distribution, frequency and clinical implications of napkin-ring sign assessed by multidetector computed tomography. *J Cardiol*, 2013.
10. Nance J.W. Jr., Schlett C.L., Schoepf U.J., et al.: Incremental prognostic value of different components of coronary atherosclerotic plaque at cardiac CT angiography beyond coronary calcification in patients with acute chest pain. *Radiology*, 2012, 264: 679-90.
11. Francone M., Carbone I., Danti M., et al.: ECG-gated multi-detector row spiral CT in the assessment of myocardial infarction: correlation with non-invasive angiographic findings. *Eur Radiol*, 2006, 16: 15-24.
12. Cury R.C., Feuchtner G.M., Batlle J.C., et al.: Triage of patients presenting with chest pain to the emergency department: implementation of coronary CT angiography in a large urban health care system. *AJR*, 2013, 200: 57-65.
13. Feuchtner G.M., Plank F., Pena C., et al.: Evaluation of myocardial CT perfusion in patients presenting with acute chest pain to the emergency department: comparison with SPECT-myocardial perfusion imaging. *Heart*, 2012, 98: 1510-1517.
14. Hoffmann U., Truong Q.A., Schoenfeld D.A., et al.: Coronary CT angiography versus standard evaluation in acute chest pain. *New Engl J Med*, 2012, 367: 299-308.
15. Hulten E., Pickett C., Bittencourt M.S., et al.: Outcomes after coronary computed tomography angiography in the emergency department: a systematic review and meta-analysis of randomized, controlled trials. *J Am Coll Cardiol*, 2013, 61: 880-892.
16. Hoffmann U., Bamberg F.: Is computed tomography coronary angiography the most accurate and effective noninvasive imaging tool to evaluate patients with acute chest pain in the emergency department?: CT coronary angiography is the most accurate and effective noninvasive imaging tool for evaluating patients presenting with chest pain to the emergency department. *Circulation Cardiovascular Imag*, 2009, 2: 251-263; discussion 263.
17. Hulten E., Pickett C., Bittencourt M.S., et al.: Meta-analysis of coronary CT angiography in the emergency department. *Eur Heart J Cardiovasc Imag*, 2013.

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Prosthetic heart valve assessment: a novel application for cardiac CT

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This article is a brief summary of the presentation about prosthetic heart valve (PHV) imaging by CT given by the author at the recent cardiac-CT course 2013 in Brussels.

Heart valve disease (stenosis or insufficiency) is common and affects mainly the aortic and mitral valve. There is no known method (medication, lifestyle or otherwise) that halts or reverses the disease process. If the is valve severely stenotic or insufficient, heart valve replacement (or repair in case of mitral valves) with a PHV is inevitable (1).

Two types of prosthetic heart valves are used: mechanical and biological PHV. Mechanical PHV are composed of metal alloys and/or carbon whereas biological PHV are composed of pericardium or animal tissue. Biological PHV do often have a supporting frame work that contains metal elements. Mechanical PHV are designed to last lifelong but also require lifelong anticoagulation therapy. Biological PHV have the advantage of being much less thrombogenic and thus do not require anticoagulation. However, they are prone to wear and have a limited (10-20 years) lifespan.

Although often being a lifesaving intervention, having a PHV presents the patient with a chronic disease with associated morbidity (bleeding due to anticoagulation, endocarditis and prosthesis dysfunction) and reduced life expectancy (1). Other modes of PHV dysfunction include obstruction by pannus formation underneath the PHV and thrombosis.

Echocardiography and fluoroscopy (for mechanical PHV) are the techniques used for PHV assessment (1, 2). Unfortunately they are often unable to determine the cause of PHV dysfunction (2). There is a role for cardiac CT to assess PHV and determine the cause of dysfunction as a complementary technique to echocardiography and fluoroscopy (3, 4).

PHV imaging by CT

Image quality

In the last 5 years the abilities of CT for PHV assessment have become subject of intense research. Our own research line on PHV imaging combines in-vitro and patient studies. The in-vitro studies use a dedicated perfusion set-up to optimize scan protocols aimed to reduce radiation exposure and at the same time reduce PHV induced artefacts.

Using this set-up we have demonstrated that most PHV types generate only a limited amount of artefacts and have a good image quality on CT (Figure 1) (5). Artefacts can be reduced using prospective acquisitions, higher KV settings and iterative reconstruction (6-8). Only Bjork Shiley and Sorin mono leaflet PHV that contain cobalt chromium generate extensive artefacts that prohibits assessment with CT (3,5).

Obstructive dysfunction

Obstructive dysfunction of a PHV manifests itself as an increased pressure gradient over the PHV on echocardiography (1, 2). The most important etiologies that need to be differentiated between are pannus, thrombus and patient prosthesis mismatch. The latter is basically

Fig. 1. — Volume rendered CT images of a bileaflet Carbomedics PHV and a monoleaflet Medtronic Hall PHV.

too small a PHV for the size of the patient and is a diagnosis by exclusion. Differentiation between thrombus and pannus is difficult by echocardiography but clinically extremely important (2). Pannus requires reoperation whereas thrombosis can be treated with thrombolysis. CT is able to visualize both pannus and thrombus and the location of the lesion can be used to discriminated between both (9). However, no data on the diagnostic accuracy of CT is available from large patient series yet.

Endocarditis

Endocarditis is an especially devastating complication after PHV implantation that is associated with high mortality and morbidity. CT is helpful to establish the presence and extent of periannular complications such as mycotic aneurysms (10). Due to the complex anatomy, CT has an advantage over echocardiography due to its ability to reconstruct images in any desired imaging plane. This information can be vital to the surgeon to optimize pre-operative planning.

Guidelines

So what are the current recommendations for the use of CT for PHV assessment? The 2010 appropriate use criteria state that the use of CT is appropriate for "Characterization of prosthetic cardiac valves" (11): In the most recent ESC guideline on valvular heart disease the authors state: "CT provides useful additional information if valve thrombus or pannus are suspected (1). In our review article (4) we propose a flowchart for the use of CT depending on the specific etiology of PHV dysfunction.

Conclusion

PHV assessment is a promising new application for cardiac CT that can provide complementary information to echocardiography and fluoroscopy. CT can be especially valuable to determine the cause of obstructive PHV dysfunction and determine the extent of PHV endocarditis.

Acknowledgements

The work presented is performed by the valve imaging group in the University Medical Center Utrecht and the Academical Medical Center Amsterdam that is composed of Radiologists, Cardiologists and Cardiac Surgeons.

References

1. Vahanian A., et al.: Guidelines on the management of valvular heart disease (version 2012): Joint Task Force on the Management of Valvular Heart Disease of the ESC and the EACTS. *Eur Heart J*, 2012, 33: 2451-2496.
2. Girard S.E., Miller F.A. Jr., Orszulak T.A., Mullany C.J., Montgomery S., Edwards W.D., Tazelaar H.D., Malouf J.F., Tajik A.J. Reoperation for prosthetic aortic valve obstruction in the era of echocardiography: trends in diagnostic testing and comparison with surgical findings. *J Am Coll Cardiol*, 2001, 37: 579-84.
3. Habets J., Mali W.P.Th.M., Budde R.P.J.: MDCT angiography in the evaluation of prosthetic heart valve dysfunction. *Radiographics*, 2012, 32: 1893-905.
4. Habets J., Budde R.P.J., Symersky P., Brink van den R.B.A., Mol de B.AJ.M., Mali W.P.Th.M., Herwerden van L.A., Chamuleau S.A.J.: Diagnostic challenges in evaluation of left-sided prosthetic heart valve dysfunction. *Nat Rev Cardiol*, 2011, 17: 466-78.
5. Symersky P., Budde R.P.J., Prokop M., Mol de B.A.J.M.: Multidetector-Row computed tomography imaging characteristics of mechanical prosthetic valves. *J Heart Valve Disease*, 2011 20: 216-222.
6. Habets J., Symersky P., Mol de B.A.J.M., Mali W.P.Th.M., Leiner T., Budde R.P.J.: A novel iterative reconstruction algorithm allows reduced dose multidetector-row CT imaging of mechanical prosthetic heart valves. *Int J Cardiovasc Imag*, 2012, 28: 1567-75.
7. Symersky P., Habets J., Westers P., Mol de B.A.J.M., Prokop M., Budde R.P.J.: Prospective ECG-triggering reduces prosthetic heart valve induced artifacts compared with retrospective ECG-gating on 256-slice CT. *Eur Radiology*, 2012, 22: 1271-7.
8. Habets J., Symersky P., Leiner T., Mol de B.A.J.M., Mali W.P.Th.M., Budde R.P.J.: Artifact reduction strategies for prosthetic heart valve CT imaging. *Int J Cardiovasc Imaging*, 2012, 28: 2099-2108.
9. Symersky P., Budde R.P.J., Mol de B.A.J.M., Prokop M.: Comparison of multidetector-row computed tomography to echocardiography and fluoroscopy for the evaluation of patients with mechanical prosthetic valve obstruction. *Am J Cardiol*, 2009, 104: 1128-34.
10. Fagman E., Perrotta S., Bech-Hanssen O., Flinck A., Lamm C., Olaison L., Svensson G.: ECG-gated computed tomography: a new role for patients with suspected aortic prosthetic valve endocarditis. *Eur Radiol*, 2012, 22: 2407-14.
11. Taylor A.J., Cerqueira M., Hodgson J.M., Mark D., Min J., O'Gara P., et al.: ACCF/SCCT/ACR/AHA/ASE/ASNC/NASCI/SCAI/SCMR 2010 appropriate use criteria for cardiac computed tomography. *J Am Coll Cardiol*, 2010, 56: 1864-94.

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