8

Non-Invasive Imaging of the Coronary Arteries

Giuseppe Maiolino, MD

Michael Poon, M D

Executive Summary

Coronary computed tomography angiography (CTA) and magnetic resonance angiography (MRA) are two rapidly developing imaging techniques utilized for non-invasive assessment of atherosclerotic and non-atherosclerotic coronary artery disease. Both tools are still facing tough challenges secondary to the small dimensions of the coronary vessels and to respiratory and cardiac motion. Coronary CTA is rapidly evolving with an improved ability to detect coronary stenoses in both native and graft vessels, as well as offering an often ideal method of evaluating coronary anomalies. On the other hand, coronary MRA is still suffering from the lack of adequate spatial and temporal resolution that is required for everyday clinical coronary imaging. This chapter summarizes some of the current common clinical utilities of cardiac CTA and MRA as well as the training criteria for both cardiac imaging modalities.

Introduction

Invasive coronary angiography (ICA) is an expensive procedure that carries a small, but potentially serious risk of a major complication including death [1]. Moreover, at least 20% of patients who undergo coronary angiography have normal appearing coronary arteries [2], thus limiting the benefit from this potentially risky procedure. Therefore, non-invasive assessment of atherosclerotic and non-atherosclerotic coronary artery disease (CAD) is an exciting frontier in cardiovascular medicine that has attracted both invasive and non-invasive cardiovascular specialists, as well as many preventive and public health specialists.

The two competing imaging techniques recently developed for this purpose, namely coronary computed tomography angiography (CTA) and magnetic resonance angiography (MRA), are still facing tough challenges secondary to the small dimensions of the coronary vessels and to respiratory and cardiac motion. Coronary CTA is rapidly evolving with improved ability to detect coronary stenoses in both native and graft vessels, as well as offering an often ideal method of evaluating coronary anomalies [3]. On the other hand, coronary MRA is still suffering from the lack of adequate spatial and temporal resolution that is required for everyday clinical coronary imaging.

Coronary Computed Tomography Angiography

The current literature on coronary CTA contains a wealth of data derived mainly from 16- and 64-slice multidetector computed tomography (MDCT) scanners. These scanners are successful in achieving diagnostic images in 93% to 100% of patients, after exclusion of the small diameter vessels (usually <1.5-2 mm). Diagnostic yield has continued to improve as CT scanner technology has progressed (Figure 1). The dual-source CT scanner, one of the most advanced CT scanners, is equipped with two 64-slice multidetectors mounted onto the gantry with an angular offset of 90°. It is achieving an unprecedented temporal resolution of 83 ms and has been shown to offer even better results with a reported diagnostic yield of 100% [4].

Assessment of Native Coronary Arteries

Currently, one of the major indications of coronary CTA is the assessment of CAD in symptomatic patients with an intermediate pre-test probability of CAD. Specifically, coronary CTA is appropriate for such patients when they have chest pain syndrome and an uninterpretable or equivocal stress test or when they have acute chest pain, but no change in their electrocardiogram or cardiac enzymes. Coronary CTA is not currently indicated for asymptomatic patients or for symptomatic patients with a high pre-test probability of having significant CAD [3].

The results of the accuracy trials with 64-slice MDCT scanners are encouraging with a per-patient analysis sensitivity of 95-100%, specificity of 90-92%, a positive predictive value (PPV) of 93-97%, and a negative predictive value (NPV) of 93-100% [5,6]. Even more encouraging is the diagnostic accuracy of the dual source CT scanner with a per-patient analysis sensitivity of 96%, specificity of 98%, a PPVof 86%, and a NPV of 99%. However, the amount of published literature and installed base on such a novel technology is still too limited to allow for any meaningful conclusions on its clinical benefit [4]. The current worldwide installed base of dual-source CT is about 220 with 65 of them in the United States.

Assessment of Coronary Artery Bypass Grafts

Assessment of the bypass grafts in patients who have had coronary artery bypass grafting (CABG) surgery is characterized by often favorable results with 64 MDCT (Figure 2). Using a per-patient analysis, coronary CTA has demonstrated a good diagnostic accuracy for evaluating graft stenosis with a sensitivity of 100%, a specificity of 89-94%, a PPV of 94-97%, and a NPV of 100% [7,8]. However, the assessment of native CAD in post-CABG patients is still limited due to the co-existence of severe native CAD with diffuse and extensive calcified plaques, as well as the often unpredictable beam hardening artifacts from the surgical clips used on the bypass grafts. As a consequence, the percentage of post-CABG patients with disease that cannot be assessed can be as high as 34% [8]. Consequently, routine use of coronary CTA for the assessment of symptomatic or asymptomatic post-CABG patients is not indicated except for noninvasive coronary artery mapping, including internal mammary artery, prior to re-op CABG, and selected cases where useful information on the patency of the bypass grafts and the native runoff vessels could affect the management decision.

Assessment of Coronary Stents

Clinical utility of coronary CTA in the assessment of stent patency and in-stent restenosis is limited using the current generation of CT scanner technology [3]. The major reasons for such limitations are also related to inadequate temporal and spatial resolution. The partial volume effect caused by the metallic stent limits the overall visibility of the inner lumen. Stent related

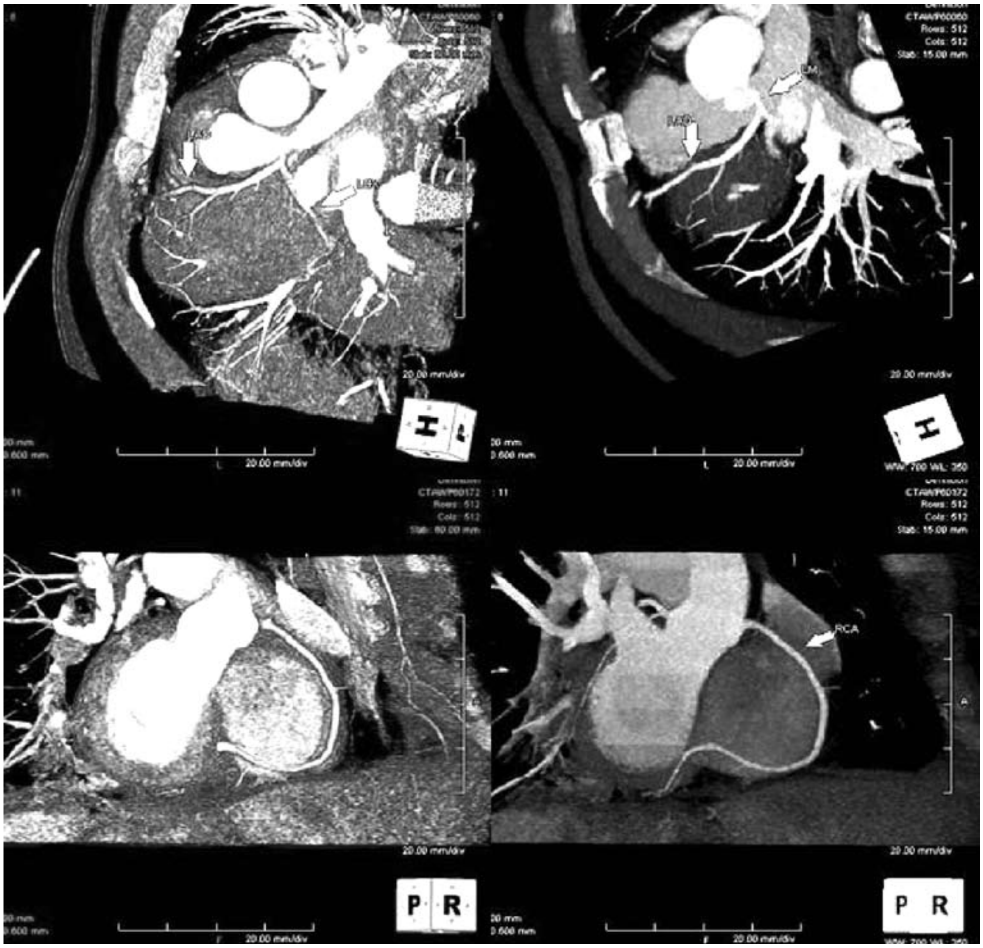

Figure 1

Top 2 panels:

3-D volume rendering (VR) (left) and maximum intensity projection (MIP) (right) images of the coronary arteries using a 128-slice dual source MDCT scanner (Somatom Definition, Siemens Medical Systems, Forchheim, Germany) demonstrate high quality, motion free left coronary arteries with excellent contrast enhancement.

Bottom 2 panels:

3-D VR and MIP images of the same heart showing an overall normal right coronary without evidence of calcified or non-calcified plaques.

Figure 2

Left panel:

3-D VR image showing a patent left internal mammary artery (LIMA) graft to the distal left anterior descending (LAD) artery. Middle Panel: 3-D VR image showing two saphenous vein (SV) grafts to the RCA and left circumflex (LCX), as well as the LIMA graft to the LAD (red arrows left to right).

Right panel:

MIP image showing a patent SV graft to the obtuse marginal (OM) branch of the LCX artery.

artifacts are also affected by the stent diameter and location, as well as the material that it is made out of. In a recently published study, nearly half of all stents with a diameter of ≤ 3 mm were not interpretable using a 16-slice MDCT scanner [9]. Even with the newer 64-slice MDCT technology, as many as 40% of stents cannot be adequately evaluated (10). Stent diameter continues to be an important determinant, with "evaluable" stents having a mean diameter of 3.28 mm compared with a mean diameter of 3.03 mm for "unevaluable" stents (p=0.0002). Likewise, stent strut thickness plays a role with Cypher® (strut thickness 0.14mm) being significantly less "evaluable" (p=0.001) than Taxus™ (strut thickness 0.13 mm). Despite the disappointingly high rate of "unevaluable" stents, the NPV and specificity in properly selected cases can still be as high as 99% and 98%, respectively (Figure 3) [10,11].

Assessment of Coronary Anomalies

Invasive coronary angiography has been the gold standard for diagnosing congenital coronary artery anomalies. However, in a recent multi-center study enrolling patients with equivocal findings at coronary catheterization, coronary CTA was able to show the origin and the entire course of the anomalous artery in all suspected individuals [12]. Thus, coronary CTA was able to provide crucial and definitive anatomical information that was helpful in the choosing of the proper therapeutic option even in those cases where invasive coronary angiographies were deemed inconclusive.

Limitations of Coronary CTA

Coronary CTA is a rapidly evolving imaging technique that, despite being non-invasive, still involves some procedural risk. Similar to that of ICA, the iodine contrast agent used in coronary CTA can cause allergic reactions and is nephrotoxic, thus limiting its use in patients with renal insufficiency. Moreover, ICA radiation dose is, in general, less than that of the current generation of 64-slice MDCT, even when using a dose-modulation approach. At the present time, cardiac CTA is covered by Medicare carriers in all 50 states. Some local coverage determinations (LCD) are more inclusive than others. Private carriers have been slow in adopting cardiac CTA awaiting more outcome data in support of the clinical usage of this imaging modality. One of the major concerns from the payer perspective is the layering of imaging modalities that may further drive up the rising healthcare cost. Based on the Model LCD and the recent published consensus document on the Appropriateness Criteria for cardiac CT and MR imaging, CTA should only be used for clinical evaluation of symptomatic patients with coronary artery disease and not for screening [3].

Coronary Magnetic Resonance Angiography

Coronary MRA has been studied during the last decade for the imaging of coronary arteries with some promising results. This investigational activity is primarily driven by the unique advantages of MRA in its absence of ionizing radiation and less nephrotoxic contrast agents.

Two of the applications of coronary MRA with the most rewarding results are the identification and assessment of congenital anomalies of the coronary arteries, where it compares favorably with invasive coronary angiography [13], and the characterization and follow-up of coronary aneurysms in Kawasaki disease [14]. Two common MR imaging techniques for the evaluation of the aorta (lumen and wall) and its branch vessels are using a combination of contrast-enhanced MRA and high resolution "black blood" imaging (Figure 4). However, coronary MRA is still technically difficult and challenging for reliable exclusion of obstructive CAD due to its low spatial resolution (between 0.5 x 0.5 x 1.5 mm [15] and 1.1 x 1.1 x 1.5 mm (16)), the tortuosity of the coronary arteries, and the respiratory and cardiac motion. The most relevant studies comparing coronary MRA with invasive coronary angiography (15-18) reported that, on a per-patient analysis, the PPV and NPV of coronary MRA were disappointingly low for the routine clinical evaluation of CAD (PPV 70% to 95% and NPV 69% to 86%). On the other hand, coronary CTA repeatedly compared favorably with coronary MRA as demonstrated in head-to-head comparisons [15,17] and in a recently published meta-analysis [19].

Training in CTA and MRA

Training guidelines have been developed by both the American College of Radiology (ACR) and the American College of Cardiology Foundation/American Heart Association (ACCF/AHA) to set the overall training standards and criteria required in order to perform and interpret cardiac CT and MR imaging. According to the ACCF/AHA guidelines [20], a training period of at least 2 months for cardiac CT and 3 months for cardiac MR is required to achieve level II (to interpret independently) and 6 months for cardiac CT and 12 months for cardiac MR to achieve level III (to direct a laboratory). The difference in training requirements between the two imaging techniques reflects the higher complexity of cardiac MR training. Prior to July 2010, the aforementioned cardiac CT training periods are not a mandatory requirement, but the training material covered for level II should include the interpretation of at least 150 studies (with 50 of the cases where the trainee is physically present during the image acquisi-

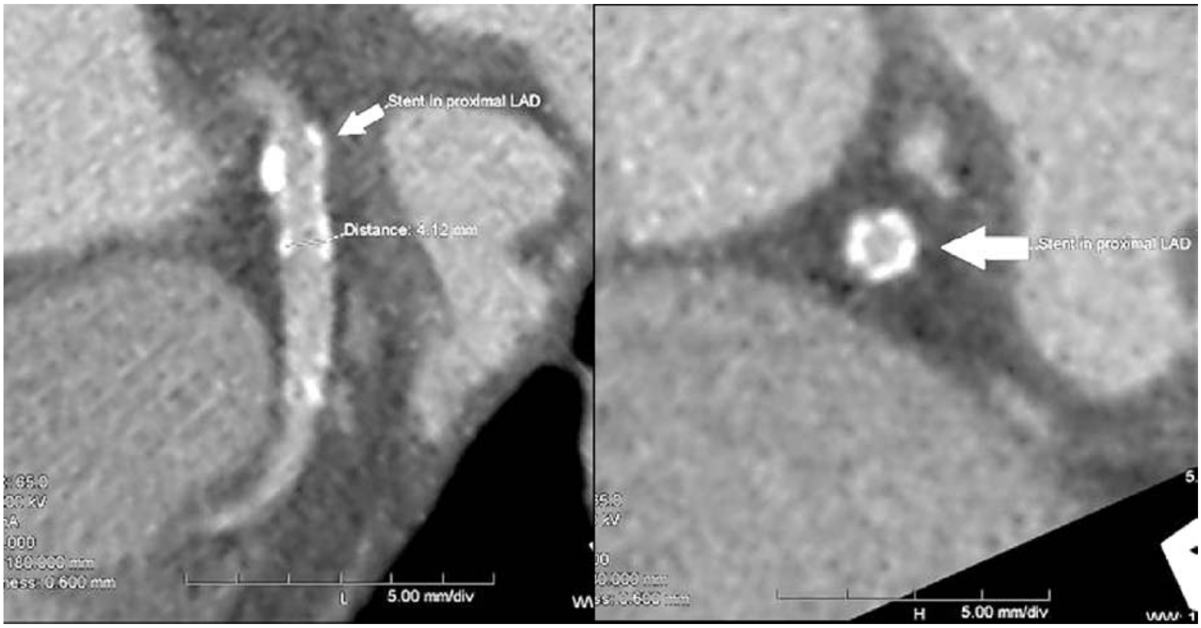

Figure 3 **Multiplanar reformatted images of the longitudinal (left) view and axial cross-sectional (right) view of a widely patent stent.**

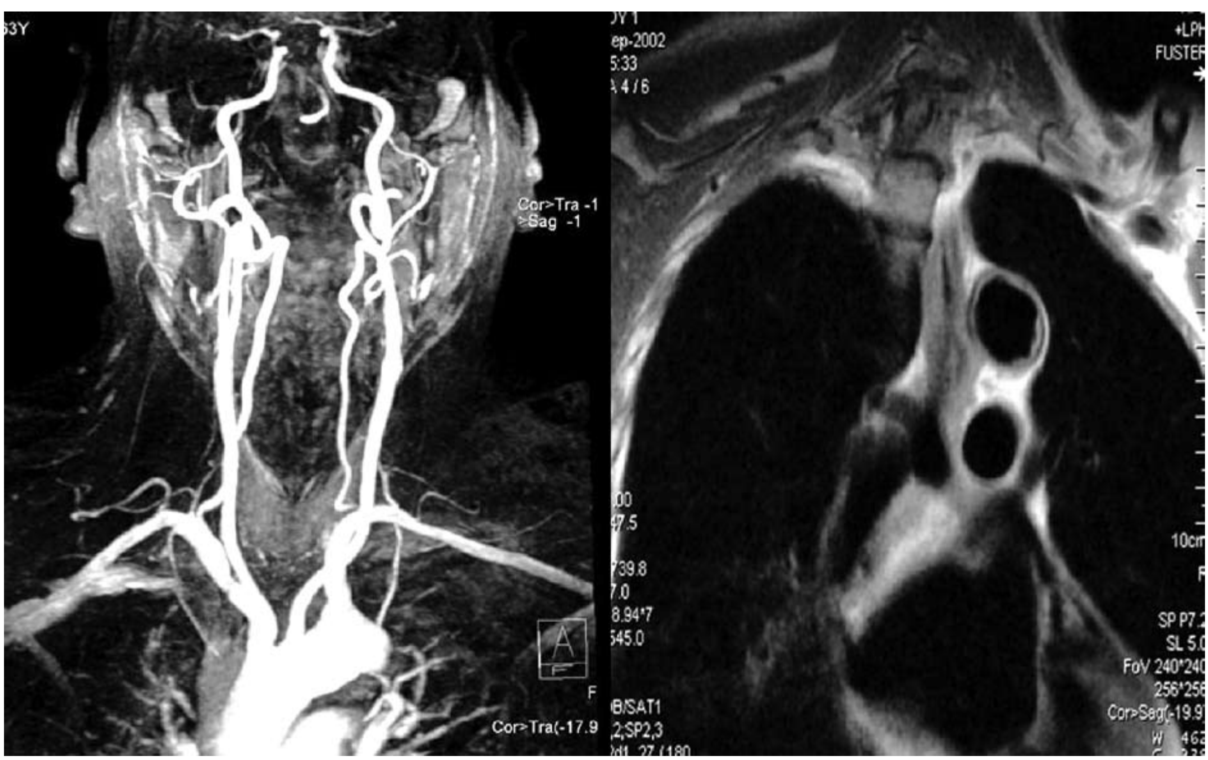

Figure 4 **High resolution contrast enhanced MRA of the aorta and its great vessels (left) and a cross-sectional high resolution MR black blood image of an atherosclerotic aortic arch (red arrow).**

tion and the trainee is responsible for the interpretation of the case), as well as attendance of at least 20 hours of CTA course work. For Level III, the number of studies interpreted is at least 300 (with 100 where the trainee is physically present) and at least 40 hours of CTA course work. The ACR training guidelines for cardiac CT are less stringent and require a total of 75 cardiac CT cases to be supervised and interpreted in addition to at least 40 hours of CME credits in course work.

Cardiologists and radiologists are both equally qualified to interpret these imaging studies. Currently, there are more radiologists than cardiologists who are doing cardiac CTA in many academic centers and out-patient imaging centers. It is anticipated that this apparent gap between the two medical specialties may narrow as more cardiologists are trained and more outcome data become available to support the widespread use of cardiac CT. Cardiologists have the advantage of being specifically trained in the evaluation and management of heart disease while radiologists are more adept in the technology of computed tomography and in the interpretation of non-cardiac thoracic findings.

Conclusion

Coronary CTA and MRA are emerging non-invasive diagnostic tools that, despite facing challenges secondary to the small dimensions of the coronary vessels and cardiac motion, can provide useful clinical information in properly selected clinical scenarios. Coronary CTA can be used reliably for ruling out significant obstructive coronary artery disease in symptomatic patients with intermediate risk for CAD prior to coronary angiography, for visualization of selected patients post-CABG or coronary stenting, and for definitive delineation of congenital coronary anomalies. Coronary MRA is still lagging behind due to the lack of sufficient spatial resolution and significant technical challenges with long scan times that make this tool impractical for every day clinical application except for the assessment of congenital coronary anomalies.

Future directions in computed tomography technology development include improvements in spatial resolution through better detector design allowing improved assessment of the coronary stents and calcium, in better arrhythmia detection and correction of misregistration of images to minimize post-processing time, in image coverage per rotation to minimize motion artifacts and radiation dose exposure, and in tissue characterization using dual energy scan. Another important improvement is the reduction of radiation dose using prospective trigger, which could make this imaging tool even more appealing and more widely clinically applicable.

References

1. Noto TJ, Jr., Johnson LW, Krone R, Weaver WF, Clark DA, Kramer JR, Jr. et al. Cardiac catheterization 1990: a report of the Registry of the Society for Cardiac Angiography and Interventions. Cathet Cardiovasc Diagn 1991; 24(2):75-83.
2. Bashore TM, Bates ER, Berger PB, Clark DA, Cusma JT, Dehmer GJ et al. American College of Cardiology/Society for Cardiac Angiography and Interventions Clinical Expert Consensus Document on cardiac catheterization laboratory standards. A report of the American College of Cardiology Task Force on Clinical Expert Consensus Documents. J Am Coll Cardiol 2001; 37(8):2170-2214.
3. Hendel RC, Patel MR, Kramer CM, Poon M, Hendel RC, Carr JC 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(7):1475-1497.
4. Scheffel H, Alkadhi H, Plass A, Vachenauer R, Desbiolles L, Gaemperli O et al. Accuracy of dual-source CT coronary angiography: First experience in a high pre-test probability population without heart rate control. Eur Radiol 2006; 16:2739-2747.
5. Mollet NR, Cademartiri F, van Mieghem CA, Runza G, McFadden EP, Baks T et al. High-resolution spiral computed tomography coronary angiography in patients referred for diagnostic conventional coronary angiography. Circulation 2005; 112(15):2318-2323.
6. Raff GL, Gallagher MJ, O'Neill WW, Goldstein JA. Diagnostic accuracy of noninvasive coronary angiography using 64-slice spiral computed tomography. J Am Coll Cardiol 2005; 46(3):552-557.
7. Malagutti P, Nieman K, Meijboom WB, van Mieghem CA, Pugliese F, Cademartiri F et al. Use of 64-slice CT in symptomatic patients after coronary bypass surgery: evaluation of grafts and coronary arteries. Eur Heart J. In press.
8. Ropers D, Pohle FK, Kuettner A, Pflederer T, Anders K, Daniel WG et al. Diagnostic accuracy of noninvasive coronary angiography in patients after bypass surgery using 64-slice spiral computed

tomography with 330-ms gantry rotation. Circulation 2006; 114:2334-2341.
9. Gilard M, Cornily JC, Pennec PY, Le Gal G, Nonent M, Mansourati J et al. Assessment of coronary artery stents by 16 slice computed tomography. Heart 2006; 92(1):58-61.
10. Rixe J, Achenbach S, Ropers D, Baum U, Kuettner A, Ropers U et al. Assessment of coronary artery stent restenosis by 64-slice multi-detector computed tomography. Eur Heart J 2006; 27(21):2567-2572.
11. Cademartiri F, Schuijf JD, Pugliese F, Mollet NR, Jukema JW, Maffei E et al. Usefulness of 64-slice multislice computed tomography coronary angiography to assess in-stent restenosis. J Am Coll Cardiol 2007; 49:2204-2210.
12. Datta J, White CS, Gilkeson RC, Meyer CA, Kansal S, Jani ML et al. Anomalous coronary arteries in adults: depiction at multi-detector row CT angiography. Radiology 2005; 235(3):812-818.
13. Post JC, van Rossum AC, Bronzwaer JG, de Cock CC, Hofman MB, Valk J et al. Magnetic resonance angiography of anomalous coronary arteries. A new gold standard for delineating the proximal course? Circulation 1995; 92:3163-3171.
14. Greil GF, Stuber M, Botnar RM, Kissinger KV, Geva T, Newburger JW et al. Coronary magnetic resonance angiography in adolescents and young adults with kawasaki disease. Circulation 2002; 105:908-911.
15. Kefer J, Coche E, Legros G, Pasquet A, Grandin C, Van Beers BE et al. Head-to-head comparison of three-dimensional navigator-gated magnetic resonance imaging and 16-slice computed tomography to detect coronary artery stenosis in patients. J Am Coll Cardiol 2005; 46:92-100.
16. Sakuma H, Ichikawa Y, Chino S, Hirano T, Makino K, Takeda K. Detection of coronary artery stenosis with whole-heart coronary magnetic resonance angiography. J Am Coll Cardiol 2006; 48:1946-1950.
17. Dewey M, Teige F, Schnapauff D, Laule M, Borges AC, Wernecke KD et al. Noninvasive detection of coronary artery stenoses with multislice computed tomography or magnetic resonance imaging. Ann Intern Med 2006; 145:407-415.
18. Kim WY, Danias PG, Stuber M, Flamm SD, Plein S, Nagel E et al. Coronary magnetic resonance angiography for the detection of coronary stenoses. N Engl J Med 2001; 345:1863-1869.
19. Schuijf JD, Bax JJ, Shaw LJ, de Roos A, Lamb HJ, van der Wall EE et al. Meta-analysis of comparative diagnostic performance of magnetic resonance imaging and multislice computed tomography for noninvasive coronary angiography. Am Heart J 2006; 151:404-411.
20. Budoff MJ, Cohen MC, Garcia MJ, Hodgson JMcB, Hundley WG, Lima AC, Manning WJ, Pohost GM, Raggi PM, Rodgers GP, Rumberger JA, Taylor AJ. ACC/AHA clinical competence statement on cardiac imaging with computed tomography and magnetic resonance: a report of the American College of Cardiology Foundation/American Heart Association/American College of Physicians Task Force on Clinical Competence (ACC/AHA Committee on CV Tomography). J Am Coll Cardiol 2005;46:383–402.