REVIEW

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Multi-Detector Computed Tomography for Assessing the Left Ventricular Function, Perfusion and Viability

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ABSTRACT

MDCT has recently been used as a diagnostic tool to evaluate coronary artery stenosis and to detect coronary artery anomalies. The accuracy of MDCT has improved the assessment of stenosis as the number of detectors has increased. In addition to its excellent role in evaluating coronary artery stenosis, MDCT can provide information regarding the left ventricular function without having to perform additional scanning, and the myocardial viability of the left ventricle can be assessed on a delayed scan. MDCT has several disadvantages such as the amount of radiation exposure and the use of an iodine contrast medium, which might cause an adverse reaction, when combined with the reconstruction of the systolic and diastolic phases and the delayed scan. Yet MDCT may provide the opportunity to evaluate the coronary anatomy, the left ventricular function and the tissue characterization in one single imaging session that lasts less than 15 minutes. **(Korean Circulation J 2007;37:191-195)**

KEY WORDS : X-ray tomography, computed ; Myocardium ; Infarction.

Introduction

Ischemic heart disease is the leading cause of morbidity and mortality in most industrialized countries.[1] The ventricular volume and myocardial mass are independent predictors of morbidity and mortality for patients suffering with coronary artery disease(CAD).[2][3] Assessing the left ventricular function is important for arriving at a correct clinical diagnosis as well as for determining the optimal management and follow-up of patients with coronary artery disease.[4] In addition, a diagnostic tool that can provide comprehensive information on the infarcted myocardium will not only help in the prognostic assessment of patients, it will also be valuable to identify those patients who will benefit from revascularization as well as to monitor the effects of new therapeutic strategies.[5] To date, magnetic resonance imaging and nuclear medicine procedures seem to be optimal for assessing ischemic heart disease as these modalities can combine the assessment of myocardial perfusion and function and they are able to assess the myocardial viability.[6][7] The recent, rapid technical development of CT scanner hardware has led to a rapid improvement of the spatial and temporal resolution and also to significantly faster cardiac scans.[5] Therefore, MDCT has become an alternative tool to assess ischemic heart disease as it can evaluate coronary artery obstruction as well as assessing the left ventricular function, perfusion and viability. In this article, we will review the MDCT studies that have evaluated the assessment of cardiac function, perfusion, and viability.

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Assessment of Left Ventricular Function

With using sub-second gantry rotation times and dedicated cardiac reconstruction algorithms on MDCT scanners, thin-section coronary angiograms have been able to depict significant proximal coronary artery stenosis in those patients who are known or suspected to have CAD.[8][9] Data acquisition can cover the entire cardiac cycle with using a spiral computed tomography technique. The diastolic and systolic image reconstructions can be generated from the same thin-section MDCT data sets with using a retrospective ECG-gating technique. A freely selectable distance from the preceding or following R-peak defines the data segment from the cardiac cycle that's used for image reconstruction.[10] For assessing only the global LV function, both the diastolic and systolic phases are required to identify the proper image reconstructions windows, with a single axial image being reconstructed every 5% of the RR interval at a representative mid-ventricular level. The appropriate reconstruction windows for the systolic and diastolic phases are visually identified as the images that show the minimum ventricular diameter(found at 25% of the RR interval) and the maximum ventricular diameter(found at 95% of the RR interval), while the thin-section secondary reformations in a true short-axis orientation in the diastolic and systolic windows allow calculation of the LV volumes and consecutively, the functional parameters(Fig. 1).[11)]

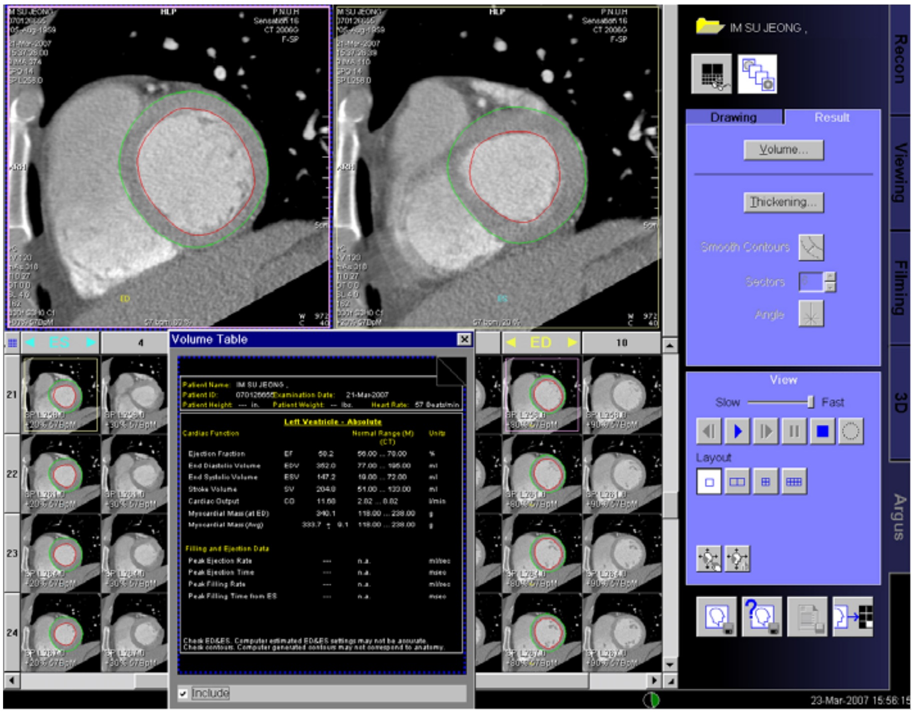

Fig. 1. This screen-shot from a Wizard workstation (Siemens, Forchheim, Germany) shows the endocardial and epicardial borders of both the end-diastolic and the end-systolic phases; these were traced semi-automatically in the short axis orientation, by using dedicated analysis software, for evaluating the left ventricular function.

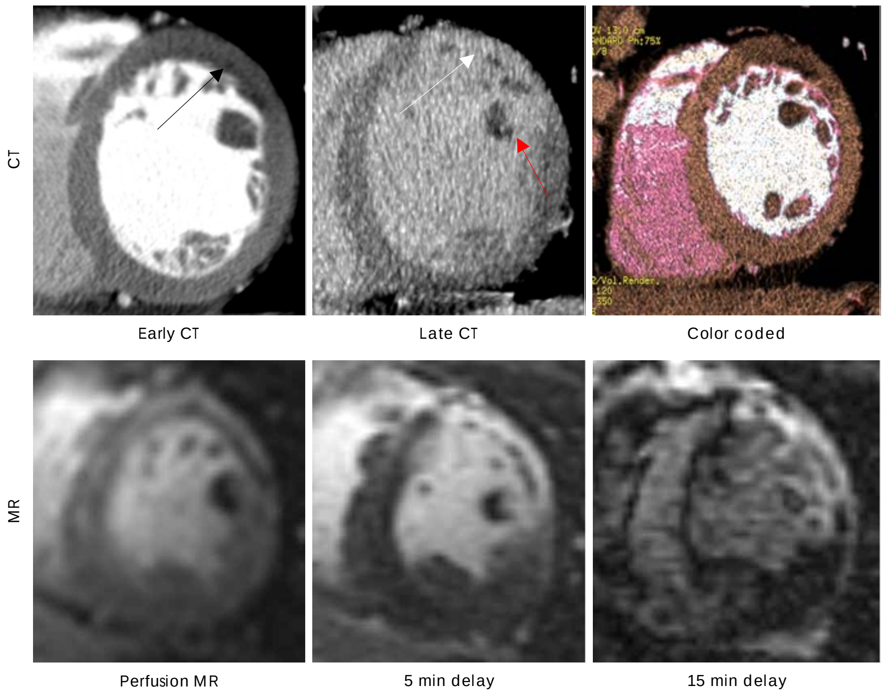

Fig. 2. In this acute MI case, the findings on the early- and late-phase CT images (perfusion defect on the early phase (black arrow) and delayed hyperenhancement (white arrow) and persistent perfusion defect (red arrow) in the papillary muscle) were well correlated with those findings on the perfusion and delayed MR images and on color-coded CT images, and so they helped to assess the infarcted area. CT: computed tomography, MI: myocardiac infaretic, MR: magnets resonance imaging.

However, it is not an easy task to determine the dedicated image sets that represent the appropriate end-diastolic and end-systolic phases on the axial image series, which are reconstructed in 5% increments of the R-R interval throughout the cardiac cycle. This is because the position of the heart changes continuously during contraction; thus, a two-phase reconstruction method can be a useful alternative tool in this situation.[12] Various invasive and noninvasive imaging modalities for the quantitative and, in part, qualitative assessment of the left ventricular performance are available and they include x-ray angiography, 2-dimensional and 3-dimensional echocardiography, MRI, EBCT and gated SPECT.[13] In addition, cardiac MRI provides excellent temporal and spatial resolution, it allows image acquisition in any desired plane and it has a high degree of accuracy and reproducibility for the quantitative measurements. Therefore, MRI is currently considered as a reference standard for assessing cardiac function.[14][15] Although MRI is already recognized as the preferred method for analyzing cardiac volume and function among the existing modalities, the ability to obtain functional information with using MDCT may have a significant clinical impact.[10] This is because MDCT can simultaneously obtain information regarding both coronary artery stenosis and the ventricular function without any additional scans. The left ventricular volume measurements from the retrospectively ECG-gated MDCT images enable volumetric and global functional analysis that is well-correlated with cardiac MRI, which has been accepted as the reference method for precisely analyzing the quantitative LV function as well as for detecting dyspnea and heart failure. MDCT also has the advantage of being fast with regard to the breath-hold data acquisition and it is suitable for use in patients with pacemakers and implanted defibrillators. As respiratory motion during MDCT examinations can affect image quality and the subsequent volume measurements, another of its advantages is that data is usually acquired within one prolonged breath hold(8-15 s), as compared with the repetitive short breatholds that are employed for cine MRI. However, the images from both modalities are susceptible to degraded image quality that's caused by any imperfect sinus rhythm. The MDCT images should theoretically be less susceptible to cardiac arrhythmias than the acquired MRI images because of the retrospective referencing of the ECG signal with performing MDCT versus the prospective referencing with performing MRI.[10] However, MDCT has several limitations: the need to administer contrast medium(which causes a volume load and might influence the LV ejection fraction on cardiac MDCT), the radiation exposure to the patient and the limited temporal resolution.[16][17] The radiation dose should be substantially reduced by the introduction of ECG-triggered tube current modulation. Several studies have demonstrated a 28% to 48% dose reduction with using ECG dose modulation, depending on the baseline heart rate.[18][19] As the temporal resolution of cardiac 4-detector row MDCT is not yet sufficient to image the coronary arteries at higher heart rates(70 bpm) without producing motion artifacts, cardiac MDCT is regularly performed after administering beta-blockers to the patient in order to reduce the heart rate.[20] Recent reports have shown that the use of beta blockers is effective to lower heart rates and reduce motion artifacts.[21] A more rapid rotation time(up to 0.33 s per rotation) has been attained with MDCT,[22] which makes it possible to shorten and stabilize the temporal resolution by using a segmental approach. Furthermore, with the introduction of dual source CT, the temporal resolution will decrease to 83 ms in the single segment reconstructions.[23]

Assessment of Perfusion and Viability

Cardiac MRI can evaluate the cardiac morphology and function, and the myocardial perfusion, viability and metabolism, as well as the coronary status.[24] An enhancing defect on the first-pass image involving the ventricular wall thickness, as noted on both the first-pass image and the delayed image of contrast-enhanced MRI, may allow the prediction of myocardial viability.[25] Park et al.[26] conducted an in vivo analysis of myocardial necrosis, as was determined by performing MRI in patients with acute myocardial infarction; they found that an infarct transmurality greater than 50% and the average necrosis index of the dysfunctional segments(ANI) might represent significant factors in the genesis of a pathologic Q wave and the endocardial sparing pattern of myocardial injury, and the latter was demonstrated by delayed enhancement. MR imaging was very useful for predicting the presence of an infarct-related artery in patients with myocardial necrosis, and this myocardial necrosis was determined by elevated levels of cardiac enzymes.[27] Early experiments performed in animal models and subsequently in human subjects have suggested that in vivo imaging for the detection, sizing and dating of myocardial infarctions is possible with using single-slice nonspiral CT systems.[28-31] The principal limitations of these early techniques were the low temporal and spatial resolution and the inadequate imaging of the inferior wall because of the inability to obtain short-axis views of the left ventricle.[32] The improved spatial and temporal resolution of MDCT has made possible using this technique to assess the myocardium. Because an MDCT coronary angiographic examination is performed during maximal enhancement of the coronary artery, assessment of the myocardium in the same scan may reflect the myocardial perfusion.[33] Gerber et al.[34] recently reported that MDCT can identify two distinct contrast-enhancement patterns of MI, that is, the early hypoenhancement as observed on the images of tissue perfusion that are obtained shortly after contrast injection, and the delayed hyperenhancement as seen on the images acquired 10 minutes after contrast injection. The location and extent of these two contrast enhancement patterns as noted on MDCT images are in good agreement with those seen on MR images, and these patterns have good interobserver, intraobserver and intrasubject reproducibility(Fig. 2). Even though the composition of the contrast materials used for MRI and CT imaging differs, a similar phenomenon occurs at the infarcted myocardium because of the similar pharmacokinetic properties of the CT and MRI contrast agents.[35)36)] In one study, because the CT examination was obtained during the rest phase, any perfusion defect distal to the coronary stenosis may not be obvious due to the compensatory vasodilatation of the distal segment.[37)] Kurata et al.[38)] demonstrated that adenosine triphosphate stress MDCT can describe both adenosine-triphosphate-induced myocardial ischemia and coronary artery stenoses in patients suffering with coronary artery disease. However, assessing myocardial perfusion by MDCT is not currently widely accepted and this is still a controversial challenge in the field of cardiac CT.[39)] Similar to MR, analysis of the early and late contrast-enhancement patterns on CT also provides valuable information on tissue viability and therefore on the likelihood of functional recovery after revascularization.[40)41)] In patients suffering with acute MI, both the extent of the early hypoenhanced region, which reflects the extent of the microvascular obstruction, and the extent of the delayed hyperenhanced region, which reflects the infarct size, have indeed been associated with an increased risk of developing complications during follow-up, including the development of adverse LV remodeling.[42)43)] Although performing a dual-phase study requires a double dose contrast media compared to a single-phase study, the X-ray exposure seems acceptable for those patients with heart disease that may be life-threatening, when considering the useful information that's obtained from the myocardial studies.[39)]

Conclusion

MDCT can provide valuable information about both the left ventricular function and the left ventricular myocardial viability, and this modality has been proven to be in excellent agreement with MRI, which is the gold standard for the assessment of both the function and viability of the left ventricular myocardium. CT coronary angiography with using MDCT has become a very reliable method for evaluating coronary artery stenosis. MDCT can give additional information regarding the left ventricular function in patients undergoing MDCT coronary angiography, as well as information on left ventricular myocardial viability if a delayed scan is performed. Therefore, MDCT can be the optimal modality for assessing ischemic heart disease.

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REFERENCES

1) Murray CJ, Lopez AD. *Alternative projections of mortality and disability by cause 1990-2020. Lancet 1997;349:1498-504.*
2) White HD, Norris RM, Brown MA, Brandt PW, Whitlock RM, Wild CJ. *Left ventricular end-systolic volume as the major determinant of survival after recovery from myocardial infarction. Circulation 1987;76:44-51.*
3) Hammermeister KE, DeRouen TA, Dodge HT. *Variables predictive of survival in patients with coronary disease: selection by univariate and multivariate analyses from the clinical, electrocardiographic, exercise, arteriographic, and quantitative angiographic evaluations. Circulation 1979;59:421-30.*
4) The Multicenter Postinfarction Research Group. *Risk stratification and survival after myocardial infarction. N Engl J Med 1983;309:331-6.*
5) Nikolaou K, Knez A, Sagmeister S, et al. *Assessment of myocardial infarctions using multidetector-row computed tomography. J Comput Assist Tomogr 2004;28:286-92.*
6) Kim RJ, Fieno DS, Parrish TB, et al. *Relationship of MRI delayed contrast enhancement to irreversible injury, infarct age, and contractile function. Circulation 1999;100:1992-2002.*
7) Kitagawa K, Sakuma H, Hirano T, Okamoto S, Makino K, Takeda K. *Acute myocardial infarction: myocardial viability assessment in patients early thereafter comparison of contrast-enhanced MR imaging with resting (201)Tl SPECT: single photon emission computed tomography. Radiology 2003;226:138-44.*
8) 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;46:552-7.*
9) Leber AW, Knez A, von Ziegler F, et al. *Quantification of obstructive and nonobstructive coronary lesions by 64-slice computed tomography: a comparative study with quantitative coronary angiography and intravascular ultrasound. J Am Coll Cardiol 2005;46:147-54.*
10) Orakzai SH, Orakzai RH, Nasir K, Budoff MJ. *Assessment of cardiac function using multidetector row computed tomography. J Comput Assist Tomogr 2006;30:555-63.*
11) Juergens KU, Grude M, Maintz D, et al. *Multi-detector row CT of left ventricular function with dedicated analysis software versus MR imaging: initial experience. Radiology 2004;230:403-10.*
12) Kim TH, Hur J, Kim SJ, et al. *Two-phase reconstruction for the assessment of left ventricular volume and function using retrospective ECG-gated MDCT: comparison with echocardiography. AJR Am J Roentgenol 2005;185:319-25.*
13) Greenberg SB, Sandhu SK. *Ventricular function. Radiol Clin North Am 1999;37:341-59.*
14) Pattynama PM, Lamb HJ, van der Velde EA, van der Wall EE, de Roos A. *Left ventricular measurements with cine and spin-echo MR imaging: a study of reproducibility with variance component analysis. Radiology 1993;187:261-8.*
15) Bellenger NG, Burgess MI, Ray SG, et al. *Comparison of left ventricular ejection fraction and volumes in heart failure by echocardiography, radionuclide ventriculography and cardiovascular magnetic resonance: are they interchangeable? Eur Heart J 2000;21:1387-96.*
16) Grude M, Juergens KU, Wichter T, et al. *Evaluation of global left*

ventricular myocardial function with electrocardiogram-gated multidetector computed tomography: comparison with magnetic resonance imaging. Invest Radiol 2003;38:653-61.

17) Ritchie CJ, Godwin JD, Crawford CR, Stanford W, Anno H, Kim Y. *Minimum scan speeds for suppression of motion artifacts in CT. Radiology 1992;185:37-42.*

18) Jakobs TF, Becker CR, Ohnesorge B, et al. *Multislice helical CT of the heart with retrospective ECG gating: reduction of radiation exposure by ECG-controlled tube current modulation. Eur Radiol 2002;12:1081-6.*

19) Gerber TC, Stratmann BP, Kuzo RS, Kantor B, Morin RL. *Effect of acquisition technique on radiation dose and image quality in multidetector row computed tomography coronary angiography with submillimeter collimation. Invest Radiol 2005;40:556-63.*

20) Schroeder S, Kopp AF, Kuettner A, et al. *Influence of heart rate on vessel visibility in noninvasive coronary angiography using new multislice computed tomography: experience in 94 patients. Clin Imaging 2002;26:106-11.*

21) Ropers D, Baum U, Pohle K, et al. *Detection of coronary artery stenoses with thin-slice multi-detector row spiral computed tomography and multiplanar reconstruction. Circulation 2003;107:664-6.*

22) Nieman K, Cademartiri F, Lemos PA, Raaijmakers R, Pattynama PM, de Feyter PJ. *Reliable noninvasive coronary angiography with fast submillimeter multislice spiral computed tomography. Circulation 2002;106:2051-4.*

23) Achenbach S, Ropers D, Kuettner A, et al. *Contrast-enhanced coronary artery visualization by dual-source computed tomography: initial experience. Eur J Radiol 2006;57:331-5.*

24) Chang HJ, Choi SI. *Era of multimodality imaging: where do we stand? Korean Circ J 2006;36:717-22.*

25) Jung SE, Youn HJ, Lee KH, Hahn ST, Hong SJ, Kim CY. *Usefulness of contrast-enhanced magnetic resonance imaging in the prediction of myocardial viability after acute myocardial infarction. Korean Circ J 2000;30:1257-63.*

26) Park YH, Kim JH, Jung JH, et al. *The meaning of pathologic Q wave in myocardial infarction assessed by magnetic resonance imaging. Korean Circ J 2004;34:945-52.*

27) Song SG, Kim JH, Kim CW, et al. *The diagnostic usefulness of cardiovscular magnetic resonance imaging for non-ischemic myocardial injury: the value of the endocardial sparing pattern on delayed enhancement. Korean Circ J 2004;34:1174-81.*

28) Huber DJ, Lapray JF, Hessel SJ. *In vivo evaluation of experimental myocardial infarcts by ungated computed tomography. AJR Am J Roentgenol 1981;136:469-73.*

29) Adams DF, Hessel SJ, Judy PF, Stein JA, Abrams HL. *Computed tomography of the normal and infarcted myocardium. AJR Am J Roentgenol 1976;126:786-91.*

30) Kramer PH, Goldstein JA, Herkens RJ, Lipton MJ, Brundage BH. *Imaging of acute myocardial infarction in man with contrast-enhanced computed transmission tomography. Am Heart J 1984;108:1514-23.*

31) Masuda Y, Yoshida H, Morooka N, Watanabe S, Inagaki Y. *The usefulness of x-ray computed tomography for the diagnosis of myocardial infarction. Circulation 1984;70:217-25.*

32) Georgiou D, Bleiweis M, Brundage BH. *Conventional and ultrafast computed tomography in the detection of viable versus infarcted myocardium. Am J Cardiol Imaging 1992;6:228-36.*

33) Ko SM, Seo JB, Hong MK, et al. *Myocardial enhancement pattern in patients with acute myocardial infarction on two-phase contrast-enhanced ECG-gated multidetector-row computed tomography. Clin Radiol 2006;61:417-22.*

34) Gerber BL, Belge B, Legros GJ, et al. *Characterization of acute and chronic myocardial infarcts by multidetector computed tomography: comparison with contrast-enhanced magnetic resonance. Circulation 2006;113:823-33.*

35) Mutzel W, Speck U, Weinmann HJ. *Pharmacokinetics of iopromide in rat and dog. Fortschr Geb Rontgenstrahlen Nuklearmed Erganzungsbd 1983;118:85-90.*

36) Allard M, Doucet D, Kien P, Bonnemain B, Caille JM. *Experimental study of DOTA-gadolinium: pharmacokinetics and pharmacologic properties. Invest Radiol 1988;23 (Suppl):S271-4.*

37) Gould KL, Lipscomb K. *Effects of coronary stenoses on coronary flow reserve and resistance. Am J Cardiol 1974;34:48-55.*

38) Kurata A, Mochizuki T, Koyama Y, et al. *Perfusion imaging using adenosine triphosphate stress multi-slice spiral computed tomography: alternative to stress myocardial perfusion scintigraphy. Circ J 2005;69:550-7.*

39) Koyama Y, Mochizuki T, Higaki J. *Computed tomography assessment of myocardial perfusion, viability, and function. J Magn Reson Imaging 2004;19:800-15.*

40) Gerber BL, Garot J, Bluemke DA, Wu KC, Lima JA. *Accuracy of contrast-enhanced magnetic resonance imaging in predicting improvement of regional myocardial function in patients after acute myocardial infarction. Circulation 2002;106:1083-9.*

41) Kim RJ, Wu E, Rafael A, et al. *The use of contrast-enhanced magnetic resonance imaging to identify reversible myocardial dysfunction. N Engl J Med 2000;343:1445-53.*

42) Gerber BL, Rochitte CE, Melin JA, et al. *Microvascular obstruction and left ventricular remodeling early after acute myocardial infarction. Circulation 2000;101:2734-41.*

43) Wu K, Zerhouni EA, Judd R, et al. *Prognostic significance of microvascular obstruction by magnetic resonance imaging in patients with acute myocardial infarction. Circulation 1998;97:765-72.*