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Korean Guidelines for the Appropriate Use of Cardiac CT

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The development of cardiac CT has provided a non-invasive alternative to echocardiography, exercise electrocardiogram, and invasive angiography and cardiac CT continues to develop at an exponential speed even now. The appropriate use of cardiac CT may lead to improvements in the medical performances of physicians and can reduce medical costs which eventually contribute to better public health. However, until now, there has been no guideline regarding the appropriate use of cardiac CT in Korea. We intend to provide guidelines for the appropriate use of cardiac CT in heart diseases based on scientific data. The purpose of this guideline is to assist clinicians and other health professionals in the use of cardiac CT for diagnosis and treatment of heart diseases, especially in patients at high risk or suspected of heart disease.

Index terms: *Guideline; Appropriateness criteria; Cardiac computed tomography*

PREFACE

Heart disease is one of the leading causes of deaths in Korea, along with malignant neoplasms and cerebrovascular diseases. The proper diagnosis and management of patients with suspected heart disease is necessary for public health care. Advances in CT technology have allowed detailed images of the heart to be obtained, which enable evaluations not only of the coronary arteries but also of other cardiac structures. Currently, multidetector CT scanners

have become widespread around Korea. The development of cardiac CT has provided a non-invasive alternative to echocardiography, exercise electrocardiography, and invasive angiography and cardiac CT continues to develop at an exponential speed even now. The appropriate use of cardiac CT may lead to improvements in the medical performances of physicians and can reduce medical costs which eventually contribute to better public health. However, until now, there has been no guideline regarding the appropriate use of cardiac CT in Korea. We intend to provide guidelines for

the appropriate use of cardiac CT in heart diseases based on scientific data. The purpose of this guideline is to assist clinicians and other health professionals in the use of cardiac CT for diagnosis and treatment of heart diseases, especially in patients at high risk or suspected of heart disease.

Methods for Establishing the Korean Guideline for Appropriate Use of Cardiac CT

This guideline was established by the Korean Society of Radiology (KSR) with participation of the Korean Society of Cardiology (KSC). Guideline development was based on the [Adaptation Process for Developing Korean Clinical Practice Guidelines] published by the Ministry of Health and Welfare in November 2011. The Clinical Practice Guideline Executive Committee of the Korean Academy of Medical Science (KAMS) was consulted for guideline development methods and a library search expert participated during the development of this guideline. The Writing Committee was comprised of 6 members appointed by KSR. The Delphi method was used to develop and establish guideline in consensus. The Rating Committee for the Delphi consensus process was comprised of 20 panelists who were appointed by the KSR and the KSC. The Writing Committee made a first draft of the Korean CT guideline by consolidating pre-existing guidelines and related study results selected for guideline adaptation. The Committee then prepared a questionnaire based on this first draft. The final guideline was established with the outcomes found by panels of the Rating Committee through three rounds of the Delphi consensus process.

For the development of this guideline, we reviewed pre-existing utilization guidelines from other countries. From national databases, 136 articles from the National Guideline Clearing House of the United States, 6 from the Scottish Intercollegiate Guidelines Network and 1 from the National Institute for Health and Care Excellence of the United Kingdom were reviewed. In addition, 98 articles from PubMed, 13 articles from the Cochrane Library, and 152 articles from Embase were reviewed. Only publications and guidelines from January 2008 to December 2011 were selected and reviewed. When guidelines had been revised, the most recent version of the guideline was selected for review. Guidelines that were established by expert consensus without being supported by objective evidence were excluded. Four pre-existing guidelines were finally selected for guideline adaptation (1-4).

To evaluate the quality of the preexisting guidelines selected for guideline adaptation, 4 of the Writing Committee members graded each guideline. An evaluation of preexisting guidelines was made with the Korean Appraisal of Guidelines for Research & Evaluation II (K-AGREE II) which was developed as a Korean version of AGREE 2.0 by the Clinical Practice Guideline Executive Committee of the KAMS. Four members of the Writing Committee evaluated the 4 selected pre-existing guidelines and a reevaluation was done of any category with a difference of more than 3 points. A standardized score was found for each section and compared. Two guidelines that had high standardized scores were finally chosen (2, 4). Tables for the K-AGREE evaluation results and guideline matrixes are given in the Supplement (in the online-only Data Supplement).

The two guidelines selected for guideline adaptation did not present levels of evidence. To develop an evidence-based guideline, literatures were searched for each scenario. PubMed and Embase were used to search for supportive evidence and the searching parameters were restricted to publications between 2000 and 2012, studies performed only on humans, and studies published in English. After developing appropriate searching formulas for each scenario, a review was done of the search results and evidential studies were selected for each related question. When a more recent systematic review or a meta-analysis study was found, previously published papers with lower levels of evidence were excluded along with case reports. Search formulas for each category are given in the Supplement (in the online-only Data Supplement). The levels of evidence given in this guideline are stratified into 3 grades and are based on the levels of evidence for prognosis and diagnosis published by the Oxford Centre for Evidence-Based Medicine in 2011. A level of evidence, of either A, B, or C, is provided for each recommendation. The following tables (Tables 1, 2) list the levels of evidence and how the evidence was graded. The appropriateness criteria was adapted from the 2010 American Heart Association cardiac CT appropriateness criteria and defined with three ratings: appropriate, uncertain, and inappropriate (Table 3). Throughout the guidelines, the criteria is marked with A (Appropriate), U (Uncertain), or I (Inappropriate) (4).

The questionnaire had 7 sections with a total 103 questions. A survey was conducted a total of 3 times, and for each question, the appropriateness of CT utilization was graded with a response scale; 1–3 points defining the use of CT as inappropriate, 4–6 points as uncertain, and 7–9

points as appropriate. When more than 75% of the panelists agreed on a grade, the panel was considered to have reached consensus for that particular question. The report form for the Delphi consensus included appropriateness criteria from other guidelines for each category, levels of evidence based on searched literature, the response scale (9-point scale), sections available for panelists to write in other comments, and a reference list for each question. In the following consensus rounds, questions for which agreement had not been reached had both their median score from the previous round and the score given in the previous round by the answering panelist listed. Response sections of questions for which agreement had been reached in previous rounds were covered in the questionnaires in the following rounds. No modifications were made to questions for which agreement had not been reached in the previous round and no other comments were written down on the questionnaires by any of the panelists. Of a total of 103 questions, a consensus was reached on 57 questions in the first survey, 36 questions in the second survey, and 10 remaining questions on the third survey. The response rate for each round was 100%. The results of the Delphi voting are included in the Supplement (in the online-only Data Supplement).

A total of 8 members, consisting of 2 members of the Clinical Practice Guideline Executive Committee of the KAMS, 3 of the KSC, and 3 of the KSR, reviewed the guidelines selected by consensus, which were later verified at an independent audit forum.

The development of the current guidelines was funded by a Grant from the National Strategic Coordinating Center for Clinical Research. The activities of the Writing Committee, the Rating Committee for the Delphi consensus and the Reviewing Committee that reviewed and verified the selected recommendations were independent of one another and none of the three Committees were influenced by the funding organization. This guideline was certified by the KSR and KCR and was also peer-reviewed by the Clinical Practice Guideline Evaluation System of the KAMS.

This guideline should be revised every 3 to 5 years, depending on the development of CT technology, changes in the healthcare environment, and further accumulation of evidence associated with cardiac CT.

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Detection of Coronary Artery Disease (CAD) in Symptomatic Patients with No Previous History of CAD

Non-Acute Chest Pain Patients Suspected of Ischemic Chest Pain

CT is known to have a high sensitivity and negative predictive value for the diagnosis of coronary artery disease (CAD) through many meta-analyses and systematic reviews (5-9). Based on previous research, in cases where performing the exercise electrocardiography (ECG) is

Table 1. Definition of Levels of Evidence

Level of Evidence	Definition
A	One Level 1 study, two or more Level 2 studies
B	One Level 2 study, two or more Level 3 studies
C	One Level 3 study, Level 4 or 5 study

Table 2. Definition of Levels of Study

Level of Study	Definition
1	Systematic review, meta-analysis
2	Individual cross sectional studies with consistently applied reference standard and blinding/inception cohort studies
3	Non-consecutive studies or studies without consistently applied reference standards/cohort study or control arm of randomized trial
4	Case-control studies, or poor or non-independent reference standard/case-series or case-control studies, or poor quality prognostic cohort study
5	Mechanism-based reasoning

Table 3. Definition of Appropriateness Criteria

Appropriateness Criteria (Score)	Definition
A-Appropriate (7–9)	Test is generally acceptable and a reasonable approach for listed indication.
U-Uncertain (4–6)	Test may be generally acceptable and may be reasonable approach for indication. Uncertainty also implies that more patient evaluation or patient information is needed to classify indication definitely.
I-Inappropriate (1–3)	Test is not generally acceptable and is not reasonable approach for indication.

impossible or ECG results are uninterpretable with low to intermediate pretest probability of CAD, cardiac CT can be used instead of noninvasive tests such as single photon emission computed tomography (SPECT) (10, 11). In patients with stable angina or with atypical chest pain, coronary CT angiography has shown a better diagnostic performance than the exercise ECG and is more cost-effective (12-14). In a study by Ghostine et al. (15) of patients with left bundle branch block who have uninterpretable ECG, coronary CT angiography was shown to be more accurate in the diagnosis of CAD. Based on these studies, coronary CT angiography can be used in patients with low and intermediate pretest probability when patients are unable to exercise or when exercise ECG results are uninterpretable. Arbab-Zadeh et al. (16) reported that the clinical efficiency of coronary CT angiography to diagnose coronary artery stenosis decreased in high-risk patients or in patients with a coronary calcium score (CAC) greater than 600. However, in a recent meta-analysis, the current CT with more than 64 slices showed a high sensitivity and specificity without any association with calcium scores and reports state that high CAC no longer limit CT performance (17).

Recommendations

Non-acute chest pain patients suspected of ischemic chest pain

1. If patients have interpretable ECG and are capable of exercise, coronary CT angiography is recommended for patients with intermediate pretest probability (Appropriateness Criteria A, Level of Evidence A), and can be considered for patients with low pretest probability (Appropriateness Criteria U, Level of Evidence A). However, coronary CT angiography is inappropriate for patients with high pretest probability (Appropriateness Criteria I, Level of Evidence B).

2. If patients have uninterpretable ECG or are unable to exercise, coronary CT angiography is recommended for patients with low to intermediate pretest probability (Appropriateness Criteria A, Level of Evidence A), and can be considered for patients with high pretest probability (Appropriateness Criteria U, Level of Evidence B).

Acute Chest Pain Patients Suspected of Acute Coronary Syndrome

For patients who visit the emergency room (ER) with acute chest pain which is clearly indicative of myocardial infarction, coronary angiography should be immediately performed. However in patients who show a normal ECG and normal myocardial enzyme levels or who have uninterpretable or non-diagnostic ECG results, coronary CT angiography has been shown to be more efficient with better cost-effectiveness and safety in the planning of future treatment (18-21). Patients who visit the hospital with acute chest pain who also have negative coronary CT angiography results are at very low risk for future major adverse cardiac events (MACEs) such as death by cardiovascular disease, myocardial infarction, and revascularization (22-24). Also, in patients with chest pain of unknown causes, the three most common fatal causes of chest pain (CAD, acute coronary syndrome, pulmonary thromboembolism) can be differentiated in a safe and effective manner by CT (25-30). In this case, CT uses a longer scanning range than conventional coronary CT angiography and the amount of radiation exposure and necessary contrast agent also increases (31). Excessive radiation exposure and the increased amount of contrast agent can become problematic and an imaging technique to overcome these issues must be applied. Even so, in a recent study done by Hoffmann et al. (32), performing coronary CT angiography on patients who visited the ER for chest pain and who were suspected of having acute coronary syndrome did help physicians make clinical decisions, but did so with an increase in radiation exposure and the number of additional testing without any reductions in cost.

Recommendations

Acute chest pain patients suspected of acute coronary syndrome

1. Coronary CT angiography is inappropriate in patients with definite myocardial infarction (Appropriateness Criteria I, Level of Evidence C).

2. In cases where myocardial infarction has been excluded and persistent ECG ST-segment elevation is observed, coronary CT angiography can be considered (Appropriateness Criteria U, Level of Evidence B).

3. In patients with acute chest pain of uncertain causes, CT can rule out pulmonary thromboembolism, aortic dissection, and acute coronary syndrome ('triple rule out') (Appropriateness Criteria A, Level of

Evidence B).

4. For acute chest pain patients with normal ECG and normal myocardial enzyme levels, coronary CT angiography is recommended (Appropriateness Criteria A, Level of Evidence A).

5. For low or intermediate pretest probability patients with uninterpretable ECG results, coronary CT angiography is recommended (Appropriateness Criteria A, Level of Evidence A) and can be considered in high pretest probability patients (Appropriateness Criteria U, Level of Evidence B).

6. In patients with non-diagnostic ECGs or unclear myocardial enzyme levels, coronary CT angiography is recommended for patients with a low or intermediate pretest probability (Appropriateness Criteria A, Level of Evidence A) and can be considered for patients with a high pretest probability (Appropriateness Criteria U, Level of Evidence B).

The recommendations by indication are listed in the Appendix (Summary Table 1).

Risk Assessment and Detection of CAD in Asymptomatic Patients with No Previous History of CAD

Coronary Calcium Scoring in Asymptomatic Patients with No Previous History of CAD

A family history of premature CAD is considered a risk factor for CAD (33, 34), and also a factor that increased the chances that atherosclerosis will develop and progress (35, 36). A family history of premature CAD, presence of coronary artery calcium, and high CAC have been strongly associated (37), and having a sibling with CAD has been more associated with developing CAD than having a parent with CAD (38).

Many studies have shown that the CAC reflects the degree of atheromatous plaque development and has a strong association with the development of CAD as well (39-45). However, measuring the CAC exposes a patient to radiation, and in men 40 years or younger, and women 50 years and younger, low calcium scores are observed. Thus, measurement of CAC is not thought necessary in young patients and is not recommended in that age group (46-48). In comparison, for men 40 years and older and women 50 years and older who are asymptomatic, the decision to measure CAC to assess risk and detect CAD should be made depending on the individual patient risk factors for cardiac

disease. Several studies have already shown that CAC predict death due to CAD and incidence of myocardial infarction better than the Framingham risk factors (49, 50). In studies where patients at intermediate risk for CAD had CAC greater than 300, the risk for angina increased every year by 2.8% and in 10 years, those intermediate risk patients had the same risk of 28% as patients at high risk for CAD (51).

In a meta-analysis of 27622 asymptomatic patients, when the CAC was 0 (11815 cases), CAD was not completely excluded but did show a very low incidence rate for the following 3 to 5 years (0.4%, 49 events). For cases with CAC between 0 and 400, the relative risk was 4.3 (95% confidence interval [CI]: 3.5 to 5.2; $p < 0.0001$). For CAC between 400 and 1000, the incidence rate was 4.6% with a relative risk of 7.2 (95% CI: 5.2 to 9.9; $p < 0.0001$) and for CAC equal or greater than 1000, the incidence rate was 7.1% with a relative risk of 10.8 (95% CI: 4.2 to 27.7; $p < 0.0001$) (52).

Recommendations

Coronary calcium scoring for risk assessment and detection of CAD in asymptomatic patients

1. Coronary calcium scoring is recommended in patients with a family history of premature CAD (Appropriateness Criteria A, Level of Evidence A).

2. Coronary calcium scoring is inappropriate in patients at low risk for CAD (Appropriateness Criteria I, Level of Evidence A).

3. Coronary calcium scoring is recommended in patient at intermediate risk of CAD (Appropriateness Criteria A, Level of Evidence A).

4. Coronary calcium scoring can be considered in patients at high risk of CAD (Appropriateness Criteria U, Level of Evidence A).

Coronary CT Angiography in Asymptomatic Patients with No Previous History of CAD

The need for a new method to assess risk for cardiovascular disease in asymptomatic patients and for the introduction of new prevention measures arose from two issues. First, a large number of patients who died suddenly from heart disease or suffered from fatal myocardial infarction had no previous symptoms of chest pain or dyspnea (53). Second, some recently published reports show that traditional risk evaluation guidelines for CAD such as the Framingham risk score and the National Cholesterol

Education Panel-III guidelines have understated the risk for heart disease in women and younger patients (54, 55).

The frequency of subclinical CAD cannot be ignored, and there are a few studies on the younger population which is generally known to be at low risk for CAD that show the effectiveness of coronary CT angiography in the risk assessment of asymptomatic patients (56, 57). However, radiation exposure due to CT is not negligible, and in some recent studies, the traditional risk factors of CAD and the CAC have been used in combination to give a similar diagnostic performance to coronary CT angiography so that coronary CT angiography is not recommended as a general screening tool in asymptomatic patients (58-61). Still, the CAC cannot help differentiate obstructive CAD and non-obstructive CAD, while coronary CT angiography can with great accuracy in high risk asymptomatic patients, another advantage of importance (62).

Recommendations

Coronary CT angiography for risk assessment and detection of CAD in asymptomatic patients
1. Coronary CT angiography is inappropriate in patients at low risk for CAD (Appropriate Criteria I, Level of Evidence A).
2. Coronary CT angiography can be considered in patients at intermediate risk for CAD (Appropriate Criteria U, Level of Evidence A).
3. Coronary CT angiography is recommended in patients at high risk for CAD (Appropriate Criteria A, Level of Evidence C).

Coronary CT Angiography after Cardiac Transplantation

Coronary allograft vasculopathy which occurs after cardiac transplantation is one of the main causes of death after transplantation and is the reason for post-operative routine coronary angiography. In a recently reported systematic review, 7 studies were analyzed that compared 16-slice CT or 64-slice CT with invasive coronary angiography or intravascular ultrasound. CT was found to have a high sensitivity and negative predictive value and was reported to be useful in the evaluation of allograft vasculopathy (63-67).

Recommendations

Coronary CT angiography after cardiac transplantation
1. Coronary CT angiography is recommended for the confirmation of coronary allograft vasculopathy after cardiac transplantation (Appropriateness Criteria A, Level of Evidence A).

The recommendations by indication are listed in the Appendix (Summary Table 2).

Detection of CAD in Various Clinical Scenarios

Heart Failure Newly Developed or Newly Diagnosed in Patients with No History of CAD

In patients newly diagnosed with heart failure, it is important to rule out ischemic heart disease and coronary CT angiography has been shown to have this utility (68-72). Bhatti et al. (73) performed a meta-analysis of 6 studies and included 452 patients to show that coronary CT angiography was useful in the diagnosis of ischemic heart disease. In a research done by Andreini et al. (70, 72) which studied patients with dilated cardiomyopathy from unknown causes, coronary CT angiography was able to safely and accurately differentiate ischemic cardiomyopathy and idiopathic dilated cardiomyopathy. The functional parameters measured by coronary CT angiography have been well correlated with MRI and echocardiography in a previous meta-analysis (74), and dysfunction in the left ventricle which can be diagnosed by CT is considered to be one of the factors predictive of poor prognosis (75, 76). There is yet to be a study on the utility of coronary CT angiography in heart failure patients with normal left ventricular ejection fraction.

Recommendations

CT to detect CAD in patients with newly developed or newly diagnosed heart failure with no previous history of CAD
1. Coronary CT angiography is recommended in patients with low or intermediate pretest probability and with reduced left ventricular ejection fraction (Appropriateness Criteria A, Level of Evidence A), and can be considered in patients with high pretest probability (Appropriateness Criteria U, Level of Evidence A).
2. Coronary CT angiography can be considered in patients with normal left ventricular ejection fraction (Appropriateness Criteria U, Level of Evidence C).

Coronary Artery Assessment Prior to Non-Coronary Cardiac Surgery

Various prospective studies have shown that coronary CT angiography can be safely used instead of invasive coronary angiography for preoperative evaluation of the coronary artery prior to non-coronary cardiac surgery (77-85). Gilard et al. (85) performed preoperative 16-slice CT on 55 patients with aortic valve stenosis to compare coronary CT angiography with invasive coronary angiography. Their research showed that coronary CT angiography has an excellent negative predictive value (100%) and that it was feasible for coronary CT angiography to rule out CAD before surgery. Catalán et al. (77) performed 64-slice CT to study patients as well. In their study, 86% of patients with a stenosis of less than 50% underwent surgery without preoperative invasive coronary angiography. None of these patients were found to be with ischemic heart disease during the follow-up period. Bettencourt et al. (86) reported that coronary CT angiography showed great accuracy in the evaluation of the coronary artery in patients before valvular surgery, and there was no difference in diagnostic accuracy even in patients with atrial fibrillation.

Recommendations
Coronary artery assessment prior to non-coronary cardiac surgery
1. Coronary CT angiography is recommended for the preoperative assessment of the coronary artery prior to non-coronary cardiac surgery (Appropriateness Criteria A, Level of Evidence A).

Arrhythmia with Etiology Still Unclear after Initial Evaluation

In arrhythmia patients, the role of CT is to confirm hypertrophic cardiomyopathy or dilated cardiomyopathy or to confirm fat in the myocardium for arrhythmogenic right ventricular cardiomyopathy (87). In atrial fibrillation patients, CT is also widely used to accurately assess the anatomic structure of the heart before radiofrequency ablation (88). Also, in patients with the left bundle branch block, coronary CT angiography has been used to rule out CAD (15). Initial studies reported that the diagnostic accuracy of coronary CT angiography decreased in cases of arrhythmia, but due to advances in CT technology, coronary CT angiography still shows a high diagnostic accuracy in the evaluation of left bundle branch block patients and atrial

fibrillation patients (15, 89). However, there still have not been many studies on the role of coronary CT angiography in the assessment of arrhythmia with unclear etiology or in the assessment of patients who have experienced syncope.

Recommendations
CT to find the cause of arrhythmia
1. Coronary CT angiography is inappropriate in cases of newly developed atrial fibrillation (Appropriate Criteria I, Level of Evidence C).
2. Coronary CT angiography can be considered for non-sustained ventricular tachycardia (Appropriateness Criteria U, Level of Evidence C).
3. Coronary CT angiography can be considered in cases of syncope (Appropriateness Criteria U, Level of evidence C).

Elevated Troponin Levels of Uncertain Clinical Significance

Elevations in troponin levels have been associated with increased rates of myocardial infarction, heart failure, and death (90). In cases of myocarditis, abnormal ECG results and increases in troponin levels can be observed and must be distinguished from changes occurring from myocardial infarction. Coronary CT angiography and delayed-phase cardiac CT can help differentiate myocardial infarction and myocarditis (91, 92). In patients complaining of acute chest pain, a study using both high-sensitivity troponin-T and coronary CT angiography was able to show that left ventricle mass, ejection fraction, and regional wall motion abnormalities were also related to increases in high-sensitivity troponin-T levels along with coronary artery stenosis (93). However, there has not been that much study on what role coronary CT angiography plays in cases where troponin levels are elevated without any other evidence of acute coronary syndrome.

Recommendations
Elevated troponin levels of uncertain clinical significance
1. Coronary CT angiography can be considered in cases where troponin levels are elevated with no other evidence of acute coronary syndrome or with no symptoms of CAD (Appropriateness Criteria U, Level of Evidence C).

CT before Percutaneous Coronary Intervention (PCI)

Many reports have shown that performing coronary CT angiography prior to percutaneous coronary intervention (PCI) is beneficial in patients with chronic total occlusion of the coronary artery (93-103). Choi et al. (94) reported that other than the duration of occlusion, the length of a lesion and the high CT number inside a lesion were predictive factors of PCI failure. Soon et al. (100) reported that if a lesion had a high calcium percentage, there was a high chance that PCI would fail. In a study by Yokoyama et al. (101), occluded blood vessels were confirmed by CT and CT was beneficial to PCI success. Besides chronic total occlusion, coronary CT angiography has recently been reported to help predict myocardial infarction that might occur after revascularization (104). Watabe et al. (104) reported that when positive remodeling and spotty calcification were confirmed on the atheromatous plaque with coronary CT angiography before PCI, myocardium necrosis occurred with higher frequency after revascularization.

Recommendations
CT before PCI
1. Coronary CT angiography is recommended in the evaluation of coronary artery lesions (e.g., chronic total occlusion, bifurcation lesion) before PCI (Appropriateness Criteria A, Level of Evidence B).

The recommendations by indication are listed in the Appendix (Summary Table 3).

Use of CT According to Different Test Results

Use of Coronary CT Angiography According to Exercise ECG Results

The exercise ECG is the standard evaluation test for ischemic heart disease and is used frequently for screening purposes (105, 106). The benefits of the exercise ECG have been proven for typical chest pain and in patients with intermediate pretest probability for CAD, but the exercise ECG is also known for reduced accuracy in patients with low pretest probability for CAD with no typical symptoms (107-109). If a patient continues to suffer from typical chest pain or have his/her symptoms worsen despite having negative exercise ECG results, a noninvasive examination should be performed. In these cases, coronary CT angiography looks to play a big role in patient evaluation (110-112).

Research shows that coronary CT angiography has a better diagnostic accuracy for CAD than the exercise ECG in stable angina patients (110, 113, 114). When the exercise ECG was negative, CT showed the post-test probability for significant CAD increase from 58% to 91%, and when the exercise ECG was positive, the post-test probability increased from 89% to 99% (113). In patients with chest pain with intermediate pretest probability, using the coronary CT angiography with the exercise ECG leads to an anatomical evaluation as well as a functional evaluation and can increase the diagnostic accuracy of CAD (114). Patients who cannot undergo the exercise ECG test or who have non-diagnostic results have been found to have similar MACEs occurring as patients diagnosed with stable angina. Coronary CT angiography provides an alternative to patients who cannot exercise or who have uninterpretable ECG (13, 115).

The Duke Treadmill Score is based on a large population study with the exercise ECG that filtered out factors related to prognosis and can be calculated with the below formula (116, 117).

Duke Treadmill Score = Total exercise time (minutes) - 5 x (maximum net ST deviation: mm*) - 4 x Angina index during exercise**

*: The maximum net ST deviation is measured at the start of the 60–80 msec mark from the J point and is defined as 0 when less than 1 mm. Exercise time is based on the Standard Bruce protocol.

**: Angina index; 0, no angina during exercise; 1, non-limiting angina during exercise; 2, exercise limiting angina with chest pains that render continuous exercise impossible

Recommendations
Coronary CT angiography according to exercise ECG results
1. Coronary CT angiography is recommended if symptoms continue despite a previous normal exercise ECG (Appropriateness Criteria A, Level of Evidence A).
2. Coronary CT angiography is recommended for patients with intermediate risk on the Duke Treadmill Score of a previous exercise ECG (Appropriateness Criteria A, Level of Evidence B).
3. Coronary CT angiography is inappropriate if a previous exercise ECG had a Duke Treadmill Score of either low or high risk (Appropriateness Criteria I, Level of Evidence B).

Use of Coronary CT Angiography after Stress Imaging Procedures

Stress imaging procedures are widely used in cases where CAD is suspected but new problems arise if the results are equivocal or if a patient has symptoms that are discordant with the results. Also, even when a patient has symptoms with abnormalities confirmed on the stress imaging procedure, very few cases are actually diagnosed as CAD and treated with an invasive procedure. According to a study by de Azevedo et al. (118), 421 patients with abnormalities found on stress imaging procedures underwent coronary CT angiography and of these patients, 18% needed invasive coronary angiography. Among the medicated patient group (82%), 6 patients received invasive coronary angiography and only one patient received coronary revascularization. Therefore, the role of coronary CT angiography can be considered quite significant in this patient group.

In about 10% of stress imaging procedures, equivocal results are observed and in most of those cases, invasive coronary angiography is additionally performed to rule out CAD (119, 120). Despite not yet establishing the role of coronary CT angiography, recently published studies state that about 70% of patients who have equivocal stress imaging procedure results do not have CAD detected by coronary CT angiography and these patients do not need invasive coronary angiography. Only about 30% of the other group of patients with CAD detected by coronary CT angiography underwent revascularization (118, 121). In this case, an additional coronary CT angiography may be useful because nuclear imaging methods have high false-positive and false-negative rates (122, 123). In a study by Cole et al. (124), among 206 patients with equivocal or inconclusive results, only 32% of patients underwent revascularization after coronary CT angiography. In a prospective study by Abidov et al. (125), 199 patients who had inconclusive or equivocal results for stress imaging procedures were followed up for two years after undergoing coronary CT angiography. The 93 patients diagnosed as normal on the initial CT had no MACEs and revascularization was only performed in patients with significant stenosis observed on CT. Thus, CT enabled accurate prediction of prognosis in 99% of the patients and most patients were able to avoid invasive coronary angiography that would have been performed for diagnostic purposes. Also, while clinical symptoms, exercise ECG results, and stress imaging procedures showed a weak association with CAD confirmed by invasive coronary angiography, CT results showed a

strong association (118, 126). The more severe the CAD state was on CT, the more MACEs occurred, which proved that coronary CT angiography could play an important role in predicting patient prognosis (118, 126). By using coronary CT angiography as a gate keeper to invasive coronary angiography, it is possible for patients to avoid unnecessary invasive coronary angiography performed for diagnostic purposes and this is also more cost-effective (125).

Recommendations
Coronary CT angiography after stress imaging
1. Coronary CT angiography is recommended when there are discordant results for the exercise ECG and the stress imaging procedures (Appropriateness Criteria A, Level of Evidence B).
2. Coronary CT angiography is recommended for cases in which results for the stress imaging studies are equivocal or mild (Appropriateness Criteria A, Level of Evidence B).
3. Coronary CT angiography is inappropriate when results for the stress imaging studies are moderate or severe (Appropriateness Criteria I, Level of Evidence B).

Use of Coronary CT Angiography after Coronary Calcium Scoring

Many studies have shown that the CAC is a strong prognostic factor of CAD (44, 45, 127-129). Budoff et al. (44) in a large cohort study showed through long-term follow-up that the CAC is an independent risk factor that predicts death from CAD, and stated that a CAC greater or equal to 10 could be a prognostic factor. According to Raggi et al. (128), the higher the CAC is, the higher probability of acute coronary syndrome occurring and in the St. Francis Heart study which followed 4900 patients for 4.3 years, a CAC of 400 or more was shown to increase the probability of death by CAD and myocardial infarction 30 times the normal rate (39). In comparison, when the CAC was 0, CAD could not be fully ruled out; however, the probability of CAD occurring was extremely low (127, 129).

Many studies have also reported that calcification of the coronary artery affects the image quality of coronary CT angiography and lowers its diagnostic accuracy (130-135). This is because artifacts from the coronary artery calcification increase the false-positive or negative rate (131, 133, 135-138) or increase the number of unassessable

segments (130, 132). In a meta-analysis done to see how much coronary artery calcification affected the diagnostic accuracy of coronary CT angiography, a high CAC was found not to significantly affect the sensitivity or accuracy of coronary CT angiography, but to significantly decrease specificity (131, 137, 139). In another report, a CAC greater than 600 had a lower negative predictive value than a CAC less than 600. Thus, CT was thought to be beneficial when the pretest probability was either low or intermediate or when the CAC was zero (16, 140). However, in a recent meta-analysis, current 64-slice CT shows a high sensitivity and specificity for CAD without any association to the CAC, which suggests that current CT technology is no longer limited by the CAC (17).

Recommendations

Coronary CT angiography after coronary calcium scoring

1. Coronary CT angiography can be considered in patients who have had a CAC of 0 for the past 5 years or more (Appropriateness Criteria U, Level of Evidence A).
2. Coronary CT angiography is inappropriate in patients who have had a CAC higher than 0 for the past two years or more (Appropriateness Criteria I, Level of Evidence A).
3. Coronary CT angiography is recommended in symptomatic patients with a CAC less than or equal to 400 (Appropriateness Criteria A, Level of Evidence A).
4. Coronary CT angiography can be considered in symptomatic patients with a CAC of 400 or higher (Appropriateness Criteria U, Level of Evidence A).

Use of Coronary CT Angiography after Stress Imaging Procedures or Coronary Angiography

In patients without specific symptoms or who have stable symptoms, coronary CT angiography has yet to show its usefulness in periodic repeated examinations.

Recommendations

Coronary CT angiography after stress imaging procedures or coronary angiography

1. Periodic repeated use of coronary CT angiography is inappropriate after stress imaging procedures or coronary angiography in asymptomatic patients or patients with stable symptoms with no known history

of CAD (Appropriateness Criteria I, Level of Evidence C).
2. Periodic repeated use of coronary CT angiography is inappropriate after stress imaging procedures or coronary angiography in asymptomatic patients or patients with stable symptoms with known history of CAD (Appropriateness Criteria I, Level of Evidence C).
3. Coronary CT angiography is recommended in patients with normal results on previous stress imaging procedures who have new or worsening symptoms (Appropriateness Criteria A, Level of Evidence C).
4. Coronary CT angiography can be considered in patients who have had abnormalities detected on previous stress imaging procedures who have new or worsening symptoms (Appropriateness Criteria U, Level of Evidence C).

The recommendations by indication are listed in the Appendix (Summary Table 4).

Risk Assessment in Patients without Acute Heart Disease before Non-Cardiac Surgery

Low-Risk Surgery

Non-cardiac surgeries can be classified into categories of low-risk, intermediate-risk, and high-risk according to the degree of risk exposed to the heart during the surgery. High-risk procedures are surgeries that have a myocardial infarction or cardiogenic death rate of more than 5%. Intermediate-risk procedures have a risk of 1–4%, and low-risk procedures have a risk of less than 1%. Endoscopic procedures, cataract surgery, breast surgery, and etc. are considered low-risk procedures. In low-risk surgeries, cardiac examinations are not generally considered necessary before surgery (141-146).

Recommendations

Preoperative coronary CT angiography prior to low-risk non-cardiac surgeries

1. Coronary CT angiography is inappropriate for risk assessment prior to low-risk non-cardiac surgeries (Appropriateness Criteria I, Level of Evidence C).

Intermediate-Risk Surgery

Surgery for the abdominal and thoracic cavity, head and neck, carotid artery, and musculoskeletal system

are all considered surgeries of intermediate risk. A 1% to 4% risk of myocardial infarction or cardiogenic death has been reported for intermediate-risk surgeries. In patients with reduced functional capacity or symptoms, additional examinations must be performed according to the presence of clinical risk factors (147). When a patient has more than 3 clinical risk factors, the cardiogenic risk associated with surgery increases and a noninvasive stress imaging procedure is recommended (141, 142). Currently used noninvasive examinations are SPECT and stress echocardiography. Some of the latest studies have focused on the potential of coronary CT angiography as a noninvasive detection tool. Kaneko et al. (148) showed that SPECT and coronary CT angiography could be useful screening techniques in patients suspected of CAD who underwent non-cardiac surgeries. They reported that the diagnostic performance of coronary CT angiography was similar to invasive coronary angiography. In another study by Chae et al. (149), coronary CT angiography was shown to be useful in the preoperative cardiac evaluation of recipients of living donor liver transplantation who had poor systematic conditions.

Recommendations

Preoperative coronary CT angiography prior to intermediate-risk non-cardiac surgeries

1. Coronary CT angiography is inappropriate when there are no clinical risk factors (Appropriateness Criteria I, Level of Evidence C).
2. Coronary CT angiography is inappropriate in patients with functional capacity more than 4 METs (Appropriateness Criteria I, Level of Evidence C).
3. Coronary CT angiography can be considered in patients with more than one clinical risk factor and with functional capacity less than 4 METs (Appropriateness Criteria U, Level of Evidence C).
4. Coronary CT angiography is inappropriate in asymptomatic patients with normal results from an exercise ECG or coronary angiography performed in the past year, or who have undergone coronary revascularization in the past year (Appropriateness Criteria I, Level of Evidence C).

*MET: estimated metabolic equivalent of exercise, refer to Supplement (in the online-only Data Supplement) for more information

Vascular Surgery

Any surgery of the aorta or other major blood vessels or peripheral arteries is considered as a non-cardiac surgery of high-risk (141, 142, 145). As previously mentioned, if a patient has poor functional capacity or if there are three or more clinical risk factors in symptomatic patients, risks associated with surgery increase and a noninvasive stress test is recommended. Abir et al. (150) found that prior to vascular surgery, a history and physical examination could categorize patients by risk and beta-blockers could be administered to patients at low risk without noninvasive tests, while patients at intermediate or high risk were recommended for noninvasive cardiac examinations before surgery. Also in patients who underwent intermediate- and high-risk non-cardiac surgery, performing preoperative noninvasive stress tests was found to reduce the length of hospital stays and increase the one-year survival rate (151).

Recommendations

Preoperative coronary CT angiography prior to vascular surgery

1. Coronary CT angiography is inappropriate for patients without any clinical risk factors (Appropriateness Criteria I, Level of Evidence C).
2. Coronary CT angiography is inappropriate for patients with a functional capacity more than 4 METs (Appropriateness Criteria I, Level of Evidence C).
3. Coronary CT angiography can be considered for patients with one or more clinical risk factors and with a functional capacity less than 4 METs (Appropriateness Criteria U, Level of Evidence C).
4. Coronary CT angiography is inappropriate in asymptomatic patients with normal exercise ECG or coronary angiography performed in the past year, or who have undergone coronary revascularization in the past year (Appropriateness Criteria I, Level of Evidence C).

*MET: estimated metabolic equivalent of exercise, refer to Supplement (in the online-only Data Supplement) for more information

The recommendations by indication are listed in the Appendix (Summary Table 5).

Risk Assessment after Coronary Revascularization

Patients Suspected of Ischemic Chest Pain after Coronary Revascularization

Occlusion of the graft vessel has been observed in about 10% of cases during coronary artery bypass graft surgery (CABG) or right after. During a ten year follow-up period, occlusion was reported in 59% of vein grafts and 17% of artery grafts (152-154). In a systematic review, the diagnostic performance of 64-slice CT for post CABG patients suspected of ischemic chest pain was studied. For total occlusion of graft vessels or for stenosis of more than 50% of the graft vessels, CT showed very high diagnostic accuracy; a sensitivity of 97.6%, a specificity of 96.7%, a positive predictive value of 92.7%, and a negative predictive value of 98.9% (155-160).

There have been many studies on the evaluation of stents after PCI for myocardial infarction patients and in a meta-analysis of 14 recent studies (895 patients, 1447 stents, average diameter 3.1 mm), it was possible to evaluate 91.4% of the included stents with CT and in-stent restenosis (ISR) was reported in approximately 20% of the entire group. For the discovery of ISR, 64-slice CT showed excellent diagnostic performance with a sensitivity of 91%, a specificity of 91%, a positive predictive value of 68%, and a negative predictive value of 98%. However, when including stents that could not be evaluated with CT, values dropped with the sensitivity becoming 87%, the specificity becoming 84%, the positive predictive value 53%, and the negative predictive value 97%. The biggest factor to decide the diagnostic value of CT in stent evaluation was the diameter of the stent. CT showed a high diagnostic accuracy in stents with a diameter of 3 mm or more and other factors such as stent material and strut thickness affected CT performance (161-166).

Recommendations
Coronary CT angiography in patients suspected of ischemic chest pain after coronary revascularization
1. CT is recommended in the evaluation of graft patency in patients suspected of ischemic chest pain after CABG (Appropriateness Criteria A, Level of Evidence A).
2. CT is recommended in the evaluation of stents with a diameter 3 mm or larger in patients suspected of ischemic chest pain after PCI (Appropriateness Criteria A, Level of Evidence A).

3. CT can be considered in stents with a diameter smaller than 3 mm or of unknown diameter for patients suspected of ischemic chest pain after PCI (Appropriateness Criteria U, Level of Evidence A).

Asymptomatic CABG Patients

Progression of CAD or recurrence of angina due to graftvessel stenosis after CABG during the follow-up period has been studied and angina recurrence was observed in 20–30% of cases in the first year after CABG. The recurrence rate rose to 40% on the sixth year after surgery, and during the follow-up period, about 50% of the patients suspected of angina had symptoms due to the progression of their original CAD (154, 167). Therefore, it has become important to find a method to detect angina recurrence during the follow-up period after CABG or to find a method to evaluate prognostic factors or assess the need to repeat surgery. Also, assessing graft vessels after surgery and possible occlusions of the original coronary artery by CT are also critical issues. Combined research results show that the recurrence rates of myocardial infarction increase greatly after 5 years due to progression of graft occlusion or due to progression of the original CAD. Therefore, patients for whom 5 years have passed since surgery should undergo a noninvasive examination, such as CT even if they are without any particular symptoms (157-160).

Recommendations
Asymptomatic CABG patients
1. CT is recommended in asymptomatic patients if more than 5 years have passed since CABG was performed (Appropriateness Criteria A, Level of Evidence A).
2. CT can be considered in asymptomatic patients if it has been less than 5 years since CABG was performed (Appropriateness Criteria U, Level of Evidence A).

Asymptomatic Patients with Coronary Artery Stents

Percutaneous coronary intervention was long considered off-limits to patients with significant left main (LM) disease for whom CABG could be performed. However, several studies have shown that PCI and CABG show similar safety, and in the MAIN-COMPARE study done by 12 of Korean hospitals, 2240 patients with LM disease were enrolled (168). In this 3-year retrospective study, there was no significant difference between PCI and CABG in death,

myocardial infarction, and stroke and PCI was proven to be a safe procedure that could replace CABG (169, 170). However, in the SYNTAX study (171) and the PRECOMBAT study (172), difficulties were reported with revascularization due to stent re-stenosis after PCI. Also, after using a drug-eluting stent in revascularization of the LM coronary artery and observing sudden deaths and fatal myocardial infarction due to stent re-stenosis after revascularization of the LM coronary artery (173-175), a need has arisen to find a way to routinely check for stent re-stenosis after PCI with clinical observation (176). Based on this need, recent research has used coronary CT angiography to evaluate larger diameter coronary artery stents for the LM coronary artery or left anterior descending coronary artery. In LM coronary artery stents with or without extension into a single side branch, a 98% accuracy was observed and an 83% accuracy was observed in LM coronary artery stents with extension into a bifurcation. In measuring stent diameter or area, CT has also shown measurements that correlate greatly with intravascular ultrasound, the method most widely and accurately used for such measurement (177). However, in measuring the minimum inner area of the stents, CT has a tendency to underestimate values compared to intravascular ultrasound (178).

> **Recommendations**
> *Asymptomatic patients with coronary artery stents*
> 1. CT is recommended for patients with a LM coronary artery stent 3 mm or larger in diameter (Appropriateness Criteria A, Level of Evidence A).
> 2. CT is inappropriate for asymptomatic patients with a stent 3 mm or larger in diameter in anywhere else then the LM coronary artery (Appropriateness Criteria I, Level of Evidence C).
> 3. CT is inappropriate if a stent with a diameter less than 3 mm or with an unknown diameter is placed in a vessel other than the LM coronary artery (Appropriate Criteria I, Level of Evidence C).

The recommendations by indication are listed in the Appendix (Summary Table 6).

Evaluation of Heart Structure and Function

Congenital Heart Disease in Adults

Cardiac CT is useful in the diagnosis of coronary artery anomaly because it can clearly show the origin of the coronary artery and its course and also because it can simultaneously show the aorta, pulmonary artery, and the rest of the heart structure (179-182). Cademartiri et al. (183) used 64-slice CT in a retrospective study to reveal the frequency of major coronary artery abnormalities found and to report CT features. In a comparison of CT and invasive coronary angiography, cardiac CT accurately diagnosed coronary artery anomalies (184-186). Also, poor prognosis was predicted by CT for certain coronary artery anomalies (187, 188). Lee et al. (187) stated that when the right coronary artery originated from the left aortic sinus between the aorta and the pulmonary artery, prognosis was worse than for those crossed between the aorta and right ventricular outflow tract.

Also, in the diagnosis of congenital anomalies in the thoracic arteries and veins, CT is known as a safe and accurate method of diagnosis, especially because it has the advantage of being able to show clinically important surrounding structures (e.g., trachea and esophagus) along with related blood vessels (189-191). Cardiac CT has high spatial resolution and because it is easy to observe both the pulmonary artery and pulmonary vein, it is useful in the diagnosis of congenital heart disease in adults (192-196). Patients who suffer from congenital heart disease normally survive into adulthood after surgery which makes it even more important to accurately assess the anatomy of cardiovascular structures after surgery. CT provides the means to do this through imaging diagnosis (197-200). With CT, it is possible to measure the volume of the right ventricle after surgery (200), or to measure the calcification of the graft used in surgery (199).

> **Recommendations**
> *Cardiac CT in adults with congenital heart disease*
> 1. Cardiac CT is recommended in the assessment of congenital anomalies of the coronary artery or other parts of the thoracic arteries or vessels (Appropriateness Criteria A, Level of Evidence A).
> 2. Cardiac CT is recommended in adults with complex congenital heart diseases (Appropriateness Criteria A, Level of Evidence A).

Evaluation of the Ventricular Structure and Systolic Function

Many studies have proven that CT has diagnostic value in evaluating the left ventricle function in comparison

to echocardiography, MRI, and ventriculography (201-204). Greupner et al. (205) compared CT, ventriculography, 2-dimensional ultrasound, and 3-dimensional ultrasound with MRI as the reference standard. They found that 64-slice CT more accurately evaluated left ventricle function than ventriculography or echocardiography. Other researchers also showed that CT was useful in evaluating the function of the left ventricle in patients with cardiomyopathy or valvular disease (206-208), and reported on the feasibility using CT in the evaluation of the diastolic function of the left ventricle (209). However, the use of CT is restricted by radiation exposure and the use of contrast agents. At the current time, there is no sufficient evidence to recommend CT as a primary evaluation tool for the left ventricle function. Still, in acute chest pain patients, evaluating regional wall motion abnormalities in the ventricle is beneficial in improving the diagnostic accuracy of coronary CT angiography (210).

Cardiac CT also shows a high accuracy when compared to cardiac MRI in the evaluation of the right ventricle function (211-213). Also, in patients suspected of arrhythmogenic right ventricular dysplasia/cardiomyopathy (ARVD/C), cardiac CT can help confirm the presence of fat in the myocardium, making it easier to reach a diagnosis (87, 214, 215). Contrast enhancement can be seen in the myocardium at the delayed phase of cardiac CT and this has been shown to represent myocardial infarction as in MRI through animal studies (216) as well as other clinical studies (217-219). Several studies have shown that CT performed directly after PCI helps predict recovery of ventricular function and ventricular remodeling by the extent and pattern of myocardial enhancement (220, 221). Cardiac CT not only provides anatomical information about the coronary artery stenosis, but also functional information about the resting perfusion state of the myocardium and regional wall motion abnormality. It even helps detect myocardial infarction through delayed myocardial enhancement. Thus, cardiac CT can be considered as a 'one-stop shop' for the diagnosis of ischemic heart diseases. However, increasing the amount of radiation exposure and used contrast agent to capture more of the cardiac cycle are drawbacks to CT as a one-stop shop for ischemic heart disease. The value of cardiac CT as a 'one-stop shop' for ischemic heart disease has not yet been studied in depth (222). Ghoshhajra et al. (223) did show in a recent study that CT with above mentioned protocols shows good performance in diagnosing ischemic heart disease, but this is still a field in need of more research.

Recommendations

Cardiac CT for evaluation of ventricular structure and systolic function

1. CT can be considered as a first-choice assessment tool for left ventricle function after acute myocardial infarction or heart failure (Appropriateness Criteria U, Level of Evidence C).
2. When images from other noninvasive imaging methods are not adequate, CT is recommended to evaluate the left ventricle function after acute myocardial infarction or in heart failure (Appropriateness Criteria A, Level of Evidence A).
3. CT is recommended to quantitatively analyze right ventricle function (Appropriateness Criteria A, Level of Evidence A).
4. In patients suspected of ARVD/C, CT is recommended to evaluate the structure of the right ventricle (Appropriateness Criteria A, Level of Evidence A).
5. If other imaging test results are insufficient or are contraindicated, CT can be considered in ischemic left-sided heart failure patients to assess myocardial viability before PCI (Appropriateness Criteria U, Level of Evidence B).
6. CT can be considered after acute myocardial infarction to evaluate the extent of myocardial infarction as well as 'no-reflow' zones (Appropriateness Criteria U, Level of Evidence C).
7. CT is recommended for comprehensive assessment as a 'one-stop shop' for ischemic heart disease (Appropriateness Criteria A, Level of Evidence C).

Evaluation of Intra- and Extracardiac Structures

The first and most important diagnostic tool of choice for the evaluation of heart valves is still echocardiography. However, when echocardiography is difficult to perform or is limited in its images, cardiac CT can play a supplementary role in diagnosis. In cases of aortic stenosis, previous studies have shown that the area of the aortic valve opening measured on CT is closely associated with the opening area measured on echocardiography (224-226). Also, by performing CT, it is possible to accurately diagnose abnormalities such as the bicuspid aortic valve (227, 228). Percutaneous aortic valve replacement has lately received much attention as a promising method of treatment and studies have shown that accurate evaluation of the aortic root is a major factor for its success (229-232). CT can use

three-dimensional data and by increasing spatial resolution, can accurately examine various geometric parameters on the aortic root. In a recent study, valvular regurgitation after the procedure was slightly better predicted by CT than by echocardiography (233). CT has also been found useful in the diagnosis of mitral valve prolapse and study of its anatomy and not just in the aortic valve (234-236). Delgado et al. (235) also reported that CT did not just show the mitral valve but that it showed the subvavular structures such as papillary muscles and chordae tendineae. Prosthetic valves can cause diverse complications such as valvular regurgitation, stenosis, infective endocarditis, etc. and therefore evaluation must be made of the structural characteristics. In mechanical valves, posterior shadowing in ultrasound creates problems in evaluating the valves or their surroundings. Recent studies have shown that cardiac CT can be beneficial in the diagnosis of prosthetic valve diseases in a diverse number of ways (237-241).

When a mass occurs near or on the heart, the primary detection method is echocardiography. However, depending on the location of the lesion, CT can play a supplementary role when echocardiography cannot characterize a certain lesion (242, 243). In patients with valvular heart disease, stroke, and atrial fibrillation, the presence of a thrombus in the atrium become of upmost interest. CT helps to evaluate the presence or absence of thrombi and also helps to differentiate false-positive lesions (e.g., spontaneous echo contrast in the left atrium) from thrombi (244, 245). Not only can cardiac CT show the anatomy of a normal pericardium, it can also show the area of a lesion three-dimensionally in constrictive pericarditis with calcifications, making it possible to plan treatment such as pericardiectomy (246-249). Also, cardiac CT allows anatomic evaluation of the pulmonary vein and cardiac veins before procedures are performed to manage arrhythmia (250-255). By observing anatomical structures before a procedure is performed, it is possible to select patients for whom certain procedures are possible and prevent complications from occurring after surgery. Also, CT plays an important role in the early detection of complications that might occur after a procedure such as cardiac tamponade, pulmonary vein stenosis, and damage to the esophagus and phrenic nerve. Cardiac CT is not only important because it allows confirmation of major structures before initial cardiac surgery, it is also important because it confirms anatomical issues that may cause serious complications when repeat surgery is needed (256-259). It is especially important

to preoperatively confirm the sternum and surrounding aorta, pulmonary vein, coronary artery, and coronary artery grafts. In a study by Kamdar et al. (258), 167 patients who had undergone CABG were found to have a variety of risky anatomical factors for repeat surgery through CT, and through this discovery, 4% had surgery canceled while 8% had changes made to their surgery plans such as incisions avoiding the median line. As advances are made to interventional procedures and equipment, treatment is based more on procedures than on open heart surgery as it was in the past. One example of this is for atrial septal defects and aorta stenosis. Quaife et al. (260) showed that CT images actually had a higher correlation with the actual size of a septal defect than those of transesophageal echocardiography done to assess atrial septal defects with balloon sizing using intracardiac echocardiography, the reference standard.

Recommendations

Evaluation of intra- and extracardiac structures

1. Cardiac CT is recommended when valvular disease is suspected and other noninvasive test methods are not appropriate (Appropriateness Criteria A, Level of Evidence A).
2. Cardiac CT is recommended when prosthetic valve dysfunction is suspected and no other noninvasive test methods are appropriate (Appropriateness Criteria A, Level of Evidence A).
3. Cardiac CT can be considered as a primary method of evaluating the presence of cardiac mass (tumor or emboli) (Appropriateness Criteria U, Level of Evidence C).
4. Cardiac CT is recommended when evaluating cardiac mass (tumor or emboli) that cannot be assessed with other noninvasive methods (Appropriateness Criteria A, Level of Evidence A).
5. Cardiac CT is recommended in anatomic assessment of the pericardium (Appropriateness Criteria A, Level of Evidence A).
6. Cardiac CT is recommended to evaluate the anatomy of the pulmonary vein before ablation therapy for atrial fibrillation (Appropriateness Criteria A, Level of Evidence A).
7. Cardiac CT is recommended to observe the anatomy of the cardiac veins before a biventricular pacemaker is inserted (Appropriateness Criteria A, Level of Evidence A).

8. Cardiac CT is recommended to confirm structural information about the blood vessels or retrosternal area before repeat surgery (Appropriateness Criteria A, Level of Evidence A).
9. Cardiac CT is recommended before procedures for atrial/ventricular septal defects or before transcatheter aortic valve implantation to confirm the anatomical structure of the heart (Appropriateness Criteria A, Level of Evidence B).

Morphologic Study of Congenital Heart Disease in Pediatric Patients

Due to developments in CT technology, it is now possible to observe and diagnose congenital malformations of cardiovascular structures in not only adults but in very small neonates (261-263). Khatri et al. (264) compared CT and cardiac catheterization and reported that most cardiac catheterization procedures could be replaced by CT. CT has also been found to sufficiently assess the anatomy of the coronary artery even in very small pediatric patients (265, 266). Another advantage is that airway stenosis developed from either the congenital heart disease or post-operative complications can be observed simultaneously (267). Also, CT has proven useful when analyzing anatomical changes that have occurred after surgery or when analyzing grafts transplanted through surgery (198, 199).

Recommendations
Pediatric patients with congenital heart disease
1. Cardiac CT is recommended when confirming anatomical malformations (e.g., coronary artery anomalies, great vessel anomalies, atrium/ventricle anomalies) in complex congenital heart disease (Appropriateness Criteria A, Level of Evidence B).
2. Cardiac CT is recommended to evaluate postoperative abnormalities (e.g., residual pulmonary artery stenosis, ventricular septal defect, bypass graft patency) in congenital heart disease patients (Appropriateness Criteria A, Level of Evidence C).

Coronary CT Angiography in Kawasaki Disease Patients

Kawasaki disease is an acute systematic vasculitis that occurs in children without a definite known etiology. It is the most common cause of acquired cardiac disease in children and can cause complications by involving the coronary artery (268). It was first reported in Japan in 1967, and has been confirmed since then to occur globally with a greater incidence rate in the Asian region (269). The highest incidence rate of Kawasaki disease is seen in Japan and in a four-year epidemiological survey between 1999 and 2002, the average incidence rate was 137.7 cases per 100000 children under 5 years of age. In an epidemiological survey in Korea, the incidence rate between 2003 and 2005 was approximately 105 cases per 100000 children under 5 years of age, a rate that was the second highest in the world after Japan (270).

For the diagnosis, treatment, and follow-up of Kawasaki disease, coronary CT angiography has been shown to be of use in several small case-control studies (271-275). Carbone et al. (276) performed 64-slice CT on 12 asymptomatic Kawasaki disease patients and were able to correctly diagnose all aneurysms, stenoses, and occlusion. They were able to prove that for follow-up of Kawasaki patients, coronary CT angiography was a better detection method than invasive coronary angiography. Peng et al. (277) proved that performing 64-slice CT was feasible in even younger Kawasaki disease patients and that CT was a noninvasive evaluation method that could be performed without pediatric patients holding their breath. In a study by Arnold et al. (278), coronary CT angiography was compared with invasive coronary angiography and coronary CT angiography also showed 100% sensitivity for coronary artery aneurysm or stenosis. While coronary CT angiography is comparable to invasive coronary angiography in accuracy when following up coronary aneurysm, the risks from accumulated radiation exposure must be considered and the role of CT in a regular follow-up schedule has yet to be studied.

Recommendations
Coronary CT angiography in Kawasaki disease patients
1. For asymptomatic Kawasaki disease patients who have not undergone previous testing, coronary CT angiography can be considered (Appropriateness Criteria U, Level of Evidence C).
2. For asymptomatic Kawasaki disease patients who have coronary aneurysm or stenosis confirmed with previous tests (coronary angiography, cardiac MRI, coronary CT angiography), coronary CT angiography is recommended for follow-up (Appropriateness Criteria A, Level of Evidence C).
3. For symptomatic Kawasaki disease patients with

no previous tests, coronary CT angiography is recommended (Appropriateness Criteria A, Level of Evidence C).

4. For symptomatic Kawasaki disease patients who have coronary aneurysm or stenosis confirmed with previous tests (coronary angiography, cardiac MRI, coronary CT angiography), coronary CT angiography is recommended for follow-up (Appropriateness Criteria A, Level of Evidence C).

The recommendations by indication are listed in the Appendix (Summary Table 7).

Supplementary Materials

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APPENDIX

Summary Table 1. Detection of CAD in Symptomatic Patients with No Previous History of CAD

			Appropriateness Criteria (Median Score)	Level of Evidence	Key References
Non-Acute Chest Pain Patients Suspected of Ischemic Chest Pain					
1	Interpretable ECG and capable of exercise	Low	U (5)	A	(11, 13)
		Intermediate	A (7)	A	(11, 13)
		High	I (3)	B	(16)
2	Uninterpretable ECG or unable to exercise	Low	A (7)	A	(11, 13)
		Intermediate	A (8)	A	(11, 13)
		High	U (5)	B	(16)
Acute Chest Pain Patients Suspected of ACS					
3	Definite myocardial infarction (MI)		I (1)	C	NA
4	Persistent ECG ST-segment elevation following exclusion of MI		U (6)	B	(18)
5	Acute chest pain of uncertain causes (pulmonary embolism, aortic dissection, and ACS ["triple rule out"])		A (7)	B	(25, 31)
6	Normal ECG and cardiac biomarkers	Low	A (7)	A	(18, 22, 23)
		Intermediate	A (7)	A	(18, 22, 23)
		High	A (7)	A	(18, 22)
7	Uninterpretable ECG	Low	A (7)	A	(18, 21, 23)
		Intermediate	A (7)	A	(18, 21, 23)
		High	U (5)	B	(18)
8	Nondiagnostic ECG or equivocal cardiac biomarkers	Low	A (7)	A	(18, 23)
		Intermediate	A (7)	A	(18, 23)
		High	U (5)	B	(18)

▢ : Pretest probability of CAD

Summary Table 2. Risk Assessment and Detection of CAD in Asymptomatic Patients with No Previous History of CAD

			Appropriateness Criteria (Median Score)	Level of Evidence	Key References
Coronary Calcium Scoring					
9	Family history of premature CHD	Low	A (7)	A	(37, 38)
10	Asymptomatic No known CAD	Low	I (3)	A	(45-48, 50, 52)
		Intermediate	A (7)	A	
		High	U (6)	A	
Coronary CT Angiography					
11	Asymptomatic No known CAD	Low	I (2)	A	(56, 57, 61, 62)
		Intermediate	U (5)	A	
		High	A (7)	C	
12	Routine evaluation of coronary arteries following heart transplantation		A (7)	A	(63)

▢ : Global CHD risk estimates

Summary Table 3. Detection of CAD in Various Clinical Scenarios

			Appropriateness Criteria (Median Score)	Level of Evidence	Key References
Newly Developed or Newly Diagnosed HF with No History of CAD					
13	Reduced left ventricular ejection fraction	Low	A (7)	A	(73)
		Intermediate	A (7)	A	(73)
		High	U (5)	A	(73)
14	Normal left ventricular ejection fraction	Low	U (5)	C	NA
		Intermediate	U (5)	C	NA
		High	U (5)	C	NA
Coronary Artery Assessment Prior to Non-Coronary Cardiac Surgery					
15	Coronary artery evaluation before non-coronary cardiac surgery	Low	A (7)	A	(77, 78, 80)
		Intermediate	A (7)	A	
		High	A (7)	A	
Arrhythmias with Etiology Still Unclear after Initial Evaluation					
16	New-onset atrial fibrillation		I (2)	C	(88)
17	Nonsustained ventricular tachycardia		U (6)	C	(87)
18	Syncope		U (4)	C	NA
Elevated Troponin Levels of Uncertain Clinical Significance					
19	Elevated troponin levels without other evidence of ACS or symptoms suggestive of CAD		U (6)	C	NA
Before PCI					
20	Evaluation of complex lesions before PCI (chronic total occlusions, bifurcation lesions, etc.)		A (8)	B	(94, 98, 104)

▢ : Pretest probability of CAD

Summary Table 4. Use of CT According to Different Test Results

				Appropriateness Criteria (Median Score)	Level of Evidence	Key References
Prior Exercise ECG					
21	Prior normal exercise ECG, continued symptoms			A (7)	A	(13, 14, 107, 110, 111, 113)
22	Prior exercise ECG results	Duke Treadmill Score	Low	I (3)	B	(14, 107, 112, 114)
			Intermediate	A (7)	B	
			High	I (3)	B	
After Stress Imaging Procedures					
23	Discordant exercise ECG and stress imaging results			A (8)	B	(107, 110, 126)
24	Prior stress imaging results		Equivocal	A (8)	B	(112, 118, 125)
			Mild	A (7)	B	
			Moderate or Severe	I (3)	B	
Prior Coronary Calcium Scoring					
25	Zero CAC > 5 y ago			U (4)	A	(129)
26	Positive CAC > 2 y ago			I (3)	A	(44, 139)
27	Diagnostic impact of CAC on the decision to perform coronary CT angiography in symptomatic patients		CAC < 100	A (8)	A	(14, 16, 44, 139, 140)
			CAC 100–400	A (8)	A	
			CAC 401–1000	U (6)	A	
			CAC > 1000	U (4)	A	
Asymptomatic or Stable Symptoms: Periodic Repeat Testing in the Setting of Prior Stress Imaging or Prior Coronary Angiography					
28	No known CAD		Last study < 2 y ago	I (2)	C	NA
			Last study ≥ 2 y ago	I (3)	C	
29	Known CAD		Last study < 2 y ago	I (2)	C	NA
			Last study ≥ 2 y ago	I (3)	C	
Evaluation of New or Worsening Symptoms in the Setting of Past Stress Imaging Study					
30	Evaluation of new or worsening symptoms		Previous stress imaging: normal	A (8)	C	NA
			Previous stress imaging: abnormal	U (6)	C	

Summary Table 5. Risk Assessment in Patients without Acute Heart Disease before Non-Cardiac Surgery

		Appropriateness Criteria (Median Score)	Level of Evidence	Key References
	Low-Risk Surgery			
31	Preoperative evaluation for non-cardiac surgery risk assessment, irrespective of functional capacity	I (2)	C	(141)
	Intermediate-Risk Surgery			
32	No clinical risk predictors	I (3)	C	(141, 149)
33	Functional capacity ≥ 4 METs	I (3)	C	
34	Functional capacity < 4 METs with 1 or more clinical risk predictors	U (6)	C	
35	Asymptomatic < 1 y following a normal coronary angiogram, stress test, or a coronary revascularization procedure	I (2)	C	NA
	Vascular Surgery			
36	No clinical risk predictors	I (2)	C	(141, 150)
37	Functional capacity ≥ 4 METs	I (2)	C	
38	Functional capacity < 4 METs with 1 or more clinical risk predictors	U (6)	C	
39	Asymptomatic < 1 y following a normal coronary angiogram, stress test, or a coronary revascularization procedure	I (2)	C	NA

Summary Table 6. Risk Assessment after Coronary Revascularization (PCI or CABG)

			Appropriateness Criteria (Median Score)	Level of Evidence	Key References
	Patients Suspected of Ischemic Chest Pain				
40	Evaluation of graft patency after CABG		A (9)	A	(157, 160)
41	Prior coronary stent with stent diameter ≥ 3 mm		A (7)	A	(161, 162)
42	Prior coronary stent with stent diameter < 3 mm or not known		U (5)	A	
	Asymptomatic CABG Patients				
43	Prior CABG	Time since CABG	≥ 5 y ago	A (7)	A	(157, 160)
			< 5 y ago	U (6)	A	
	Asymptomatic Patients with Coronary Artery Stents				
44	Prior left main coronary stent with stent diameter ≥ 3 mm		A (7)	A	(161, 162, 177, 178)
45	Stent diameter ≥ 3 mm	Time since PCI	≥ 2 y ago	I (3)	C	
			< 2 y ago	I (3)	C	
46	Stent diameter < 3 mm or not known		I (3)	C	

Summary Table 7. Evaluation of Heart Structure and Function

		Appropriateness Criteria (Median Score)	Level of Evidence	Key References
Congenital Heart Disease in Adults			
47	Assessment of anomalies of coronary arterial and other thoracic vasculatures	A (9)	A	(179, 183, 187)
48	Assessment of complex adult congenital heart disease	A (9)	A	(193, 198, 199)
Evaluation of Ventricular Structure and Systolic Function			
49	Initial evaluation of left ventricular (LV) function, following acute MI or in HF patients	U (4)	C	NA
50	Evaluation of LV function, following acute MI or in HF patients, inadequate images from other noninvasive methods	A (7)	A	(203, 205)
51	Quantitative evaluation of right ventricular (RV) function	A (7)	A	(211-213)
52	Assessment of RV morphology, suspected arrhythmogenic RV dysplasia	A (7)	A	(214, 215)
53	Assessment of myocardial viability, prior to myocardial revascularization for ischemic LV systolic dysfunction, other imaging modalities are inadequate or contraindicated	U (5)	B	(217-219)
54	To determine the location and extent of myocardial infarction including 'no-reflow' regions, post-acute MI	U (6)	C	(221)
55	Serving as an 'one-stop shop' for ischemic heart disease in diagnosis, comprehensive evaluation and treatment strategy planning in difficult cases	A (8)	C	(222)
Evaluation of Intra- and Extracardiac Structures			
56	Characterization of native cardiac valves, suspected clinically significant valvular dysfunction, inadequate images from other noninvasive methods	A (8)	A	(225, 228)
57	Characterization of prosthetic cardiac valves, suspected clinically significant valvular dysfunction, inadequate images from other noninvasive methods	A (8)	A	(228, 237-239)
58	Initial evaluation of cardiac mass (suspected tumor or thrombus)	U (4)	C	NA
59	Evaluation of cardiac mass (suspected tumor or thrombus), inadequate images from other noninvasive methods	A (8)	A	(243, 244)
60	Evaluation of pericardial anatomy	A (8)	A	(246, 248)
61	Evaluation of pulmonary vein anatomy, prior to radiofrequency ablation for atrial fibrillation	A (8)	A	(252)
62	Noninvasive coronary vein mapping, prior to placement of biventricular pacemaker	A (8)	A	(253-255)
63	Localization of coronary bypass grafts and other retrosternal anatomy, prior to reoperative chest or cardiac surgery	A (8)	A	(258, 259)
64	Anatomic assessment before percutaneous device closure of ASD or VSD or percutaneous aortic valve replacement	A (8)	B	(231-233, 260)
Morphologic Study of Congenital Heart Disease			
65	Assessment of complex congenital heart disease including anomalies of coronary circulation, great vessels, and cardiac chambers and valves	A (8)	B	(261, 263, 266)
66	Assessment of post-operative congenital heart disease, such as residual pulmonary stenosis, ventricular septal defect and patency check for Blalock-Taussig shunt	A (8)	C	(199)

Summary Table 7. Evaluation of Heart Structure and Function (Continued)

		Appropriateness Criteria (Median Score)	Level of Evidence	Key References
Coronary CT Angiography in Kawasaki Disease Patients				
67	Asymptomatic, no previous definite test (invasive angiography, MRCA or coronary CT angiography) available	U (5)	C	NA
68	Asymptomatic, previous tests (invasive angiography, CMR or coronary CT angiography) documented coronary aneurysm/ stenosis, for follow up	A (7)	C	(276, 277)
69	Symptomatic, no previous definite test available	A (7)	C	NA
70	Symptomatic, previous tests (angiography, CMR or coronary CT angiography) documented coronary aneurysm/stenosis, for follow up	A (8)	C	(276, 277)