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Update: Cardiac Imaging (IV)

Recent Scientific Evidence and Technical Developments in Cardiovascular Computed Tomography

Roy Marcus,[a] Christer Ruff,[a] Christof Burgstahler,[b] Mike Notohamiprodjo,[a] Konstantin Nikolaou,[a] Tobias Geisler,[c] Stephen Schroeder,[d] and Fabian Bamberg[a,*]

[a] Department of Diagnostic and Interventional Radiology, University of Tuebingen, Germany
[b] Department of Sports Medicine, University of Tuebingen, Tuebingen, Germany
[c] Department of Cardiology, University of Tuebingen, Tuebingen, Germany
[d] Department of Internal Medicine, Klinikum Göppingen, Göppingen, Germany

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ABSTRACT

In recent years, coronary computed tomography angiography has become an increasingly safe and noninvasive modality for the evaluation of the anatomical structure of the coronary artery tree with diagnostic benefits especially in patients with a low-to-intermediate pretest probability of disease. Currently, increasing evidence from large randomized diagnostic trials is accumulating on the diagnostic impact of computed tomography angiography for the management of patients with acute and stable chest pain syndrome. At the same time, technical advances have substantially reduced adverse effects and limiting factors, such as radiation exposure, the amount of iodinated contrast agent, and scanning time, rendering the technique appropriate for broader clinical applications. In this work, we review the latest developments in computed tomography technology and describe the scientific evidence on the use of cardiac computed tomography angiography to evaluate patients with acute and stable chest pain syndrome.

Evidencia científica reciente y avances técnicos en la tomografía computarizada cardiovascular

Palabras clave:
Angio-TC cardiaca
Síndrome coronario agudo
Dolor torácico agudo

RESUMEN

En los últimos años, la coronariografía (o angiografía coronaria) por tomografía computarizada se ha asentado cada vez más como una modalidad diagnóstica segura y no invasiva para la evaluación de la antomía del árbol arterial coronario, que aporta ventajas diagnósticas, en especial para pacientes con probabilidad pretest baja o intermedia de la enfermedad. Actualmente hay cada vez más evidencia de grandes ensayos aleatorizados sobre la influencia diagnóstica de la angiotomografía computarizada en el manejo de los pacientes con síndromes de dolor torácico agudo y crónico. Al mismo tiempo, los avances técnicos han reducido sustancialmente los efectos adversos y los factores limitantes, como la exposición a la radiación, la cantidad de medio de contraste yodado que se aplica y el tiempo de exploración, lo cual la hace apropiada para aplicaciones clínicas más amplias. En este trabajo se revisan los avances más recientes en la tecnología de la tomografía computarizada y se describe la evidencia científica existente sobre el uso de la angiotomografía computarizada cardiaca en la evaluación de los pacientes con síndromes de dolor torácico agudo y crónico.

INTRODUCTION

In 2010, 1 in of every 6 deaths in the United States of America was related to coronary heart disease with estimated direct and indirect costs of ~$204.4 billion.[1] With 6.9 million patients out of 136.3 million emergency department (ED) visits in 2011, chest pain was one of the 20 leading primary diagnostic groups.[2] However, only 17% of patients admitted to the ED met the criteria for acute coronary syndrome (ACS), while 55% showed noncardiac causes.[3] When ACS is suspected, the evaluation should include medical history, physical examination, electrocardiogram (ECG), and cardiac injury markers, such as troponin. Patients with a very low probability of myocardial infarction (MI) (< 5%) can be well identified and hence be admitted to an observation unit for further risk stratification examinations, such as exercise treadmill, cardiac single photon emission computed tomography (SPECT), cardiac magnetic resonance tomography, or stress echocardiography.[4,5]

* Corresponding author: Department of Diagnostic and Interventional Radiology, University of Tuebingen, Hoppe-Seyler Str. 3, 72076 Tuebingen, Germany.
E-mail address: fabian.bamberg@uni-tuebingen.de (F. Bamberg).

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Abbreviations

CAD: coronary artery disease
CCTA: coronary computed tomography angiography
ED: emergency department
IR: iterative reconstruction
SOC: standard of care

This approach may eventually result in increased admission rates and unnecessary noninvasive or invasive follow-up tests, which will ultimately dramatically increase costs.[6]

In the last decade, coronary computed tomography angiography (CCTA) has been established as a safe alternative modality for the evaluation of coronary artery disease (CAD), especially in patients with a low or intermediate pretest probability for coronary obstruction, which was duly endorsed by the American College of Cardiology/American Heart Association.[7] Recently, randomized trials, which compared the use of CCTA with the current standard of care (SOC), has provided increasing evidence that the application of CCTA in routine practice can safely reduce hospital stay and hospital costs.[8]

RECENT TECHNICAL DEVELOPMENT

With the introduction of multidetector technology in 1999, visualization of the coronary artery tree at low heart rates became feasible.[9] Since then, computed tomography (CT) technology has evolved rapidly, including an increasing number of detectors of up to 392 rows, the introduction of dual-source-CT technology, or increasing pitch factors, enabling image data acquisition in a single heartbeat.[10] The increasing spatial resolution of up to approximately 0.5 mm allows assessment of the coronary arteries, as well as the presence of plaque and stenosis. Major currently-available technical improvements include imaging at low voltage and high-pitch factors, as well as the introduction of iterative reconstruction (IR) algorithms (Figure 1).

LOW VOLTAGE IMAGING

Lowering the tube voltage has been introduced as a means to reduce radiation exposure in patients with lean body habitus.[11] However, at the same time, a reduction of tube voltage is associated with an increase in image noise, which may therefore impair diagnostic accuracy and could require increased tube current, which is available in more recent generations of scanners.[12] It is also known that the attenuation value of iodinated enhancement is increased in a lower tube voltage, and hence the administration of contrast media can be reduced, which particularly benefits patients with renal impairment.[13] Early multicenter and multivendor studies, such as the Protection I trial, showed a 53% reduction in radiation dose estimates with no significant impairment of diagnostic image quality when the tube voltage was lowered from 120 kV to 100 kV.[14] A recent study comparing CCTA with 3 tube voltage settings showed a significant reduction in radiation dose when comparing 70 kV with 80 kV and 100 kV (0.44 vs 0.78 and 0.92 mSv; $P < .0001$). The reduction in tube voltage was associated with a significant increase in noise in the lowest kV-setting ($P < .0497$) but with no apparent impairment in subjective and qualitative image quality. The latest study with 43 patients undergoing a CCTA examination with a tube voltage setting at 70 kV prior to the planned invasive angiography, showed very high diagnostic accuracy (sensitivity of 92.2% and specificity of 89.5%) while reducing the dose estimate to 0.2 mSv.[15]

HIGH-PITCH ACQUISITIONS

Another strategy to reduce the dose estimate is to increase the pitch,[16] which is defined as the table travel per rotation divided by the nominal slice.[17] In a single-source CT system, the pitch was limited to 1.5, due to data loss at higher pitch values. With the introduction of the dual-source-CT technology system, the pitch could be increased to over 3, as the second source/detector separately acquires the data one quarter rotation later without a gap.[18] Hence the radiation exposure can be lowered significantly using the technology, as no slice overlap is needed.[17] In a phantom and patient study, Sommer et al[19] compared the high-pitch protocol set at 3.4 with the conventional prospective triggered acquisition and the retrospective ECG gated acquisitions (pitch = 0.2). The phantom based radiation dose estimate showed the lowest value in the high-pitch protocol compared with the prospectively ECG-triggered and retrospective ECG-gated acquisition (1.21 vs 3.12 vs 11.81 mSv). In the patient substudy, the radiation dose estimate showed a similar trend (1.11 vs 4.15 vs 11 mSv; $P < .001$) and significant differences in motion-free display of coronary arteries (99% vs 87% vs 92% for the high-pitch, prospective ECG-triggered and retrospective ECG-gated acquisition, respectively). In a similar study with 50 patients, the application of the high-pitch protocol with a tube voltage at 100 kV resulted in an estimated radiation dose of 1 mSv in nonobese patients with low and stable heart rate.[20]

ITERATIVE RECONSTRUCTION TECHNIQUES

The introduction of IR techniques have had a major impact on reducing radiation exposure. Until recently, conventional CT image reconstruction from raw data attenuation measurement was based on the filtered back projection (FBP) technique.[21] Images based on FBP take into account multiple projections from different scanning angles by back-projecting raw data; however, this does not consider either the statistical noise or the X-ray beam geometry or the photon interaction with the scanned object and detector.[22] When a standard radiation dose is applied, FBP is well accepted; however, when photon density and hence radiation dose is reduced, there is an incremental increase in image noise. To overcome this problem, IR can be applied to enhance the image quality. Iterative reconstruction is based on a mathematical model, iterating the image reconstructions several times and hence generating images with lower noise.[22–24] In one study, 60 patients were referred for invasive angiography and 2 CCTA examinations: one CCTA-acquisition with conventional acquisition settings and FBP reconstruction technique and a second CCTA-acquisition with a reduction of the tube current-time product by 50% using the IR technique, showing no significant difference in diagnostic accuracy and image quality between the FBP and IR technique.[25] In a very low-dose (100 kV) study, prospectively ECG-gated CCTA images were reconstructed from the raw data using the FBP and IR techniques. The IR technique significantly improved image quality and diagnostic accuracy (sensitivity: 81% vs 69%; specificity: 97% vs 97).[26]

SCIENTIFIC EVIDENCE IN THE SETTING OF ACUTE CHEST PAIN

Acute chest pain is often a leading symptom of ACS, pulmonary embolism, aortic dissection, or even esophageal pathology. Most persons admitted to the ED with acute chest pain are routinely