Rev Esp Cardiol. 2016;69(2):188–200

Review article

Stress Computed Tomography Myocardial Perfusion Imaging: A New Topic in Cardiology

Sara Seitun,[a,*] Margherita Castiglione Morelli,[a] Irilda Budaj,[a] Sara Boccalini,[a] Athena Galletto Pregliasco,[a] Alberto Valbusa,[b] Filippo Cademartiri,[c] and Carlo Ferro[a]

[a] Department of Radiology, Interventional Radiology, IRCCS San Martino University Hospital-IST, National Institute for Cancer Research, Genoa, Italy
[b] Department of Cardiology, IRCCS San Martino University Hospital-IST, National Institute for Cancer Research, Genoa, Italy
[c] Department of Radiology, Cardiology, Erasmus Medical Center University, Rotterdam, The Netherlands

Article history:
Available online 14 January 2016

Keywords:
Computed tomography myocardial perfusion
Stress computed tomography
Dual-energy computed tomography
Myocardial perfusion imaging

ABSTRACT

Since its introduction about 15 years ago, coronary computed tomography angiography has become today the most accurate clinical instrument for noninvasive assessment of coronary atherosclerosis. Important technical developments have led to a continuous stream of new clinical applications together with a significant reduction in radiation dose exposure. Latest generation computed tomography scanners (≥ 64 slices) allow the possibility of performing static or dynamic perfusion imaging during stress by using coronary vasodilator agents (adenosine, dipyridamole, or regadenoson), combining both functional and anatomical information in the same examination. In this article, the emerging role and state-of-the-art of myocardial computed tomography perfusion imaging are reviewed and are illustrated by clinical cases from our experience with a second-generation dual-source 128-slice scanner (Somatom Definition Flash, Siemens; Erlangen, Germany). Technical aspects, data analysis, diagnostic accuracy, radiation dose and future prospects are reviewed.

Técnica de imagen de perfusión miocárdica con tomografía computarizada de estrés: un nuevo tema en cardiología

Palabras clave:
Perfusión miocárdica con tomografía computarizada
Tomografía computarizada de estrés
Tomografía computarizada de energía dual
Imágenes de perfusión miocárdica

RESUMEN

Tras su introducción hace unos 15 años, la angiografía por tomografía computarizada se ha convertido actualmente en el instrumento clínico más exacto para la evaluación no invasiva de la aterosclerosis coronaria. Los importantes avances técnicos han conducido a un torrente continuo de nuevas aplicaciones clínicas junto con una reducción significativa de la dosis de exposición a la radiación. Los escáneres de tomografía computarizada de última generación (≥ 64 cortes) brindan la posibilidad de obtener imágenes de perfusión estáticas o dinámicas durante la aplicación de estrés mediante vasodilatadores coronarios (adenosina, dipiridamol o regadenosón), combinando la información funcional y anatómica en la misma exploración. En este artículo se examina el papel emergente y el estado actual de las imágenes de perfusión miocárdica con tomografía computarizada, y se ilustra con casos clínicos de la propia experiencia con un escáner de segunda generación de 128 cortes y doble fuente (Somatom Definition Flash, Siemens; Erlangen, Alemania). Se examinan los aspectos técnicos, el análisis de los datos, la exactitud diagnóstica, la dosis de radiación y las perspectivas futuras.

INTRODUCTION

A number of advances during the last 15 years have seen coronary computed tomography angiography (CTA) become one of the mainstay diagnostic tools for noninvasive assessment of coronary atherosclerosis in patients with a low-to-intermediate probability of coronary artery disease (CAD).[1–4] Coronary CTA demonstrates high sensitivity and negative predictive value in determining significant stenosis (≥ 50% lumen reduction), approaching 100%.[1–4] However, based solely on the morphological characteristics of the coronary lesions, the hemodynamic significance of the stenosis cannot be determined, especially that of intermediate-grade stenosis (40%-70% lumen reduction), as demonstrated by studies of invasive fractional flow reserve (FFR) measurements.[5] The landmark FAME trial has demonstrated that an FFR-guided percutaneous coronary intervention approach is superior to treatment with a percutaneous coronary intervention based solely on visual angiographic assessment of coronary lesions, with an improved clinical outcome and a positive

* Corresponding author: Department of Radiology and Interventional Radiology, IRCCS San Martino University Hospital-IST, National Institute for Cancer Research, Largo R. Benzi 10, 16132, Genoa, Italy.
E-mail address: saraseitun@yahoo.com (S. Seitun).

http://dx.doi.org/10.1016/j.rec.2015.10.018
1885-5857/

Abbreviations

CAD: coronary artery disease
CTA: computed tomography angiography
CTP: computed tomography perfusion
DE: dual-energy
DSCT: dual-source computed tomography
MBF: myocardial blood flow
MRI: magnetic resonance imaging
SPECT: single-photon emission computed tomography

economic impact on health care cost.[5] To date, the 2 largest randomized controlled trials, the COURAGE[6] and BARI 2D[7] trials, have failed to show that percutaneous coronary intervention based solely on a standard visual approach is superior to optimal medical therapy in reducing mortality or recurrent myocardial infarction. Therefore, these studies suggest that functional assessment of coronary lesions may help to identify patients who may benefit from revascularization in stable CAD. Moreover, studies correlating the anatomic information of coronary CTA with single-photon emission computed tomography (SPECT) have demonstrated a moderate positive predictive value (about 50%) of CTA in determining inducible myocardial ischemia.[8,9] For these reasons, in clinical practice, morphological information obtained with coronary CTA often requires integration with functional imaging tests such as SPECT, positron emission tomography, or magnetic resonance imaging (MRI) during pharmacological stress to highlight perfusion defects, with an impact on patient management and prognosis. However, the latest-generation computed tomography (CT) scanners ($\geq$ 64 slices) allow static and dynamic CT perfusion (CTP) to be obtained during stress by using coronary vasodilator agents (adenosine, dipyridamole, or regadenoson), combining both functional and anatomical information in the same examination, which are essential in state-of-the-art patient management.[2,5] In this article, the emerging role and state-of-the-art of myocardial CTP during pharmacological stress are reviewed and illustrated by clinical cases from our preliminary experience with a second-generation 128-slice dual-source CT (DSCT) scanner (Somatom Definition Flash, Siemens; Germany). Technical aspects, data analysis, diagnostic accuracy, radiation dose and the possible future role of this innovation are reviewed.

PHYSIOPATHOLOGY OF ISCHEMIA

Myocardial perfusion is a highly regulated process influenced by numerous factors, such as epicardial vessels, resistance vessels, and endothelium.[10] At rest, the myocardium oxygen extraction rate is very high (75%-80%) and, whenever demands increase, the myocardium can supply incrementing coronary blood flow and oxygen delivery.[10] Ischemia can occur secondary to reduced coronary blood flow/perfusion pressure not compensated by the autoregulation process, which is the ability to maintain a relatively stable coronary perfusion over a wide range of perfusion pressures due to dilation of resistance vessels. Coronary blood flow at rest is not compromised by epicardial stenosis of up to 85%-90% but, in the presence of maximal hyperemia, it decreases with stenosis of $>$ 45%.[10] Moreover, the physiological effect of stenosis also depends on the degree of compensation of the distal microcirculatory bed.[10,11] The ischemic process initially involves the subendocardial layer with an endo-subpericardial front causing a cascade of physiopathological events among which perfusion

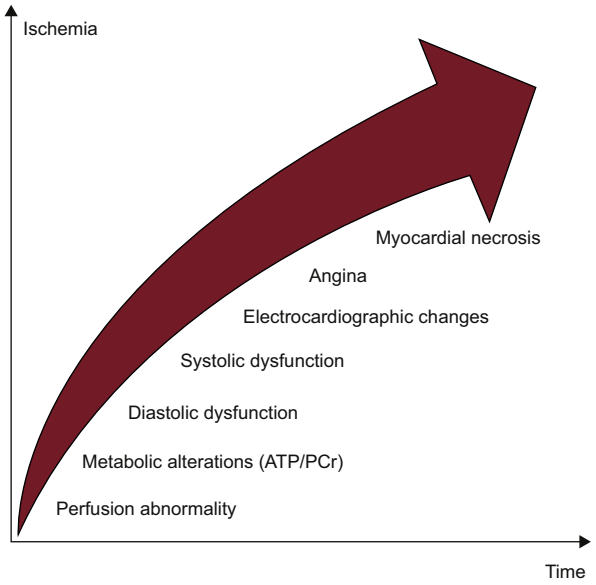

Figure 1. The ischemic cascade. ATP/PCr, adenosine triphosphate/phosphocreatine.

reduction is an early change (Figure 1).[10] For these reasons, stress tests evaluating this parameter are more sensitive in identifying hemodynamically significant stenosis than analysis of the stress-induced wall motion abnormalities or electrocardiogram (ECG) changes alone (Figure 1).[10]

ACQUISITION MODALITY

Myocardial stress CTP images can be acquired in either a static or dynamic mode. Static CTP imaging acquires a single temporal phase during the arterial first-pass of the contrast agent.[12] Among static techniques, the recently introduced dual-energy (DE) acquisition is one of the most promising techniques and consists of the use of different X-ray spectra generated by different tube voltages.[13,14] Dynamic time-resolved CTP acquisition allows the acquisition of multiple consecutive contrast-enhanced phases as the contrast bolus transits the myocardium, in a manner similar to stress-MRI.[12] By obtaining time attenuation curve (TAC) computation, dynamic acquisition enables perfusion parameters to be calculated from mathematical modeling.[9]

Monoenergetic Static Acquisition

A single stationary contrast-enhanced first-pass arterial acquisition during pharmacological stress is performed. Optimization of the timing of image acquisition is therefore crucial to acquire the dataset during the peak of myocardial enhancement.[15,16] Several acquisition techniques are available with a progressive reduction in dose profile and contrast media administration: retrospective ECG-gating (with prospective tube current modulation),[17,18] prospective ECG-gating,[19,20] and prospectively ECG-triggered high-pitch spiral acquisition implemented with the second-generation 128-slice DSCT scanner.[21,22]

Static Acquisition With the Dual-energy Technique

The DE technique allows quantitative analysis through evaluation of iodine distribution during the first-pass phase of the contrast agents based on their X-ray absorption characteristics