The Coronary Arteries

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16.1 Introduction

Magnetic resonance angiography (MRA) of the coronary arteries became possible in 1991 with the development of a new group of fast MR imaging sequences (Duerinckx 1995, 1996, 1997, 1999, 2001a, b; Wielopolski et al. 1998, 2000; Woodard et al. 1999; Dianis et al. 1998; Manning and Edelman 1993). Coronary MRA has since been used with great success in key clinical applications, such as the detection of coronary artery variants and the imaging of coronary stents and bypass grafts. The new magnetic resonance imaging (MRI) techniques also allow quantification of velocity and flow in coronary arteries. Most promising is the potential role of coronary MR angiography in screening for coronary artery lesions, which is actively being investigated.

Coronary artery disease remains the leading cause of death in the United States and is responsible for an estimated 900,000 deaths per year. The estimated cost of these deaths and the additional 1.5 million heart attacks annually exceeds $60 billion in the United States alone (American Heart Association 1996). X-ray contrast angiography is widely accepted as the definitive method to define coronary anatomy. However, given that currently more than 1 million diagnostic cardiac catheterizations are performed annually in the USA (Johnson et al. 1989) and the relative high procedural cost of $3000 to $5000, any less-expensive noninvasive alternative test would be welcome. Coronary MRA offers the potential to replace diagnostic and screening X-ray coronary angiography in the near future in selected population groups. The impact of cardiac MRI on the global cost of healthcare and the use of diagnostic tests for myocardial ischemia will be enormous. This review introduces the novice to these new cardiac MRI technologies and their proven and future applications. More advanced readers will find extensive discussions of the research and preclinical work done by many investigators since 1991.

16.1.1 What Is Coronary MRA?

Unlike other blood vessels, coronary arteries are small tortuous vessels subjected to significant physiological motion, both cardiac and respiratory, which present a tremendous challenge to conventional MRI
and MRA techniques. With the development in 1991 of a new group of fast MRI pulse sequences “reliable and reproducible” MRA of the coronary arteries has become possible and was described in the first preclinical studies published in 1993 and 1994 (MANNING et al. 1993a, b; DUERINCKX and URMAN 1994a). The term “reliable” means simply that images of good quality can routinely and reproducibly be obtained in the majority of patients. Prior to the development of these newer techniques coronary artery MRI was possible, but was much less reliable and not considered a clinical application of cardiac MRI.

Several generations of coronary MRA techniques have since been described (see Table 16.1). All techniques use ECG triggering. First-generation breath-hold techniques, as described in 1991, acquire one two-dimensional (2D) image per breath-hold and are commercially available on almost all new MRI scanners. They are robust and have been successfully used for specific clinical applications. All imagers should become familiar with their use.


<table>
<thead>
<tr>
<th>Generation</th>
<th>Principle</th>
<th>Pros and cons</th>
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<tr>
<td>First</td>
<td>One slice per breath-hold</td>
<td>2D; spatial registration problems; available on all commercial scanners</td>
</tr>
<tr>
<td>Second</td>
<td>Free-breathing</td>
<td>3D and high resolution; but long acquisition times (up to 15 min)</td>
</tr>
<tr>
<td>Third</td>
<td>3-D volume in a single breath-hold</td>
<td>3D and low spatial resolution; short acquisition times</td>
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The second generation techniques use navigator pulses for respiratory gating or triggering and are referred to as “non-breath-holding” or “free-breathing” techniques, as they do not require breath-hold ing. Although the initial implementations were somewhat unreliable, dramatic improvements have since been made. Third generation techniques allow three-dimensional (3D) volume acquisitions (multiple 2D images) in a single breath-hold, which in combination with real-time interactive slice positioning, appears very promising. MR contrast agents, real-time slice positioning, and higher-resolution acquisition schemes, such as spiral MRA, can further improve and facilitate the use of these coronary MRA techniques.

Technical progress and changes in this subfield of cardiac MRI have been so rapid that large-scale preclinical trials have not been (and probably never will be) conducted with the majority of the first and second generation coronary MRA pulse sequences as known today. In this chapter we review the development of these new cardiac MRI techniques and the initial successes with clinical applications using commercial MR scanners.

16.1.2 Clinical Indications for Coronary MRA

Coronary MRA is a cardiac MRI technique used to visualize the proximal and middle portion of most coronary arteries and some coronary artery branches. The techniques and practice of coronary MRA can easily be learned. Even though it is not equivalent to conventional X-ray-based coronary angiography, coronary MRA can and should be used for noninvasive imaging in a variety of clinical situations. We will discuss the evaluation of congenital coronary artery anomalies and the noninvasive determination of the patency of bypass grafts and coronary stents. Coronary MRA can also be used in the follow-up of known proximal coronary lesions, such as after angioplasty. However, the use of coronary MRA for blind prospective detection of unknown coronary lesions is still being evaluated. Coronary MRA techniques may become an integral part of the clinical evaluation and screening of patients with ischemic heart disease. Coronary MRI techniques appear very promising in the quantification of coronary flow and flow reserve.

16.2 Coronary MRA Techniques

Conventional cardiac-triggered MRI has provided reliable, clinically useful, diagnostic images of cardiac structures and large vessels within the thorax for many years (HIGGINS et al. 1990; HIGGINS 1992; BLACKWELL et al. 1992; DUERINCKX et al. 1994; BOGAERT et al. 1999). With conventional cardiac MRI it has been possible to visualize coronary bypass grafts, evaluate bypass graft patency, and quantitate flow in bypass grafts. Bypass grafts in general are