Special Article

Clinical Experience from 1000 Consecutive Cardiovascular MRI Cases at a Tertiary Referral Medical Center

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We present our experience from the first 1000 clinical cardiovascular magnetic resonance imaging cases performed at our institution. The case load included pediatric and adult patients with a male predominance (two thirds of the patient population). The spectrum of diseases was very broad, and included myopathic, atherosclerotic, vascular, valvular, pericardial, neoplasmatic and congenital heart disease. Our experience demonstrates the areas where cardiovascular magnetic resonance imaging has established value and suggests areas of future development.

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Cardiovascular magnetic resonance imaging (CMR), has been rapidly evolving over the last fifteen years, and has now been established as a standard clinical diagnostic tool for a variety of cardiovascular diseases. CMR is currently unequivocally the standard reference for measurement of left and right ventricular volumes, ejection fraction and mass.[1,2] CMR is also considered as the best test to visualize the location and size of myocardial scar and for many it has become the "gold standard" for the assessment of myocardial viability.[3,4] Congenital heart disease is yet another broad group of diseases where CMR has unique advantages and has become a valuable tool for initial diagnosis, decision to intervene and post-operative follow-up.[5-7]

Our institution established a CMR center in July 2002. Over the last 4.5 years we have completed over 1200 examinations that were performed for clinical indications. Here we present our experience from the first 1000 clinical cases that were completed within the first 4 years of our center's inception, in order to demonstrate the areas where CMR has established its value and acceptance and to suggest areas in which further application and development may be possible.

Methods

All examinations at our institution were performed using a superconducting 1.5 T clinical scanner (Intera, Philips Medical Systems, Best, The Netherlands) with cardiac software (v.9.0.3) and a 5-element phase-array coil. Analysis of CMR examinations was performed at a dedicated workstation (Easyvision 5, Philips Medical Systems for the period 07/2002–10/2005 and Viewforum, Philips Medical Systems from 11/2005 on).

All patients entering the scanner for a CMR examination were screened for the presence of contraindications, including pacemakers, automatic defibrillators, ocular or cochlear implants, brain clips, implanted pumps, etc., by the technologist performing the examination or the responsible physician. Whenever there were safety concerns (shrapnel, intrauterine or other uncommon implanted devices, etc.) the referring physician or the physician responsible for the device was contacted for additional information regarding the implant, and X-ray radiographic imaging was obtained if necessary.

Demographic and clinical data were collected directly from the patients and entered into a database constructed using Microsoft Access 2003®, (Microsoft Corporation, Seattle, WA). Information recorded included personal identifiers (name and surname, police card identification number, telephone number), height, weight, referring physician, presence of coronary artery disease and previous myocardial infarctions, presence of coronary risk factors including family history of coronary disease [yes/no], hypertension [yes/no], smoking [yes/no (never/former {quit <5 years / quit ≥5 years})], hypercholesterolemia [yes/no], diabetes mellitus [no/yes (type I / type II)], and presence of chest pain or dyspnea [no/yes (at rest or with mild, moderate or severe activity)]. Women were also asked whether they were menstruating. Body mass index and body surface area were automatically calculated from patients' height and weight.[8] The validity of the information reported by the patient was not compared against the hospital medical record and was not confirmed with the referring physician.

The database also included fields regarding which aspect of cardiac imaging was performed (anatomy, ventricular function, valve assessment, contrast-enhanced angiography, viability, coronary artery imaging). Numerical data representing measured values of left and right ventricular volumes and mass, and those indexed for body surface area, were manually entered from the CMR report. Left and right ventricular ejection fraction was automatically calculated using the formula:

$$\frac{\text{(end-diastolic volume – end-systolic volume)}}{\text{end-diastolic volume}} \times 100\%$$

When flow measurements were obtained, aortic and pulmonic regurgitant fraction and calculated mitral and tricuspid regurgitant fraction were entered from the CMR report.

All examinations were performed by one of two technologists (FT, AL), and/or the responsible physician (PGD). All interpretations were performed by an experienced cardiologist (PGD). For all pediatric patients of age <8 years, intravenous sedation was administered with midazolam and propofol by an experienced anesthesiologist, maintaining patients' spontaneous breathing. Patients who stated that they were claustrophobic at the time of scheduling of the CMR examination were advised to take a single dose of oral benzodiazepine immediately before the examination.

Statistical analysis

Data for each parameter that was recorded in the database were exported to Microsoft Excel 2003® (Microsoft Corporation, Seattle, WA), using simple queries. Descriptive statistics include mean values ± one standard deviation (SD), range and percent (%), as appropriate.

Results

The first 1000 CMR cases performed in our institution included 666 men (66.6%) and 334 women (33.4%). The mean age was 42 ± 22 years with a range of 0-85 years. The detailed demographics of the cohort are presented in Table 1. The number of cases per year is shown in Figure 1. In analyzing the clinical CMR caseload for the years 2002-2006, the logarithmic trendline offered the best fit (r^2=0.97), although a linear model also provided an excellent fit (r^2=0.95).

Studies were performed for evaluation of myopathic diseases (known or suspected nonischemic, hypertrophic, restrictive or infiltrative cardiomyopathy) (N=265), congenital heart disease (N=240), ischemic heart disease (N=167), valvular heart disease (N=104), diseases of the aorta (N=71), cardiac or vascular masses (N=50), pericardial disease (N=21), coronary angiography (N=17), and other indications (N=65). All patients had a gross anatomic evaluation of the chest structures. The examination included detailed anatom-

Table 1. Demographic characteristics of the initial 1000-patient cardiac magnetic resonance cohort.

Demographic characteristics	Number (%) or ± SD
Men	666 (67)
Women	334 (33)
Age (yrs)	42 ± 22
Pediatric patients (0-14 years old)	128 (13)
Adolescent or adult patients (≥14 years old)	872 (87)
Pediatric patients (≤8 years old)	67 (7)
Height (m)	1.66 ± 0.20
Weight (kg)	71 ± 23
Body mass index (kg/m2)	25 ± 8
Body surface area (m2)	1.78 ± 0.38

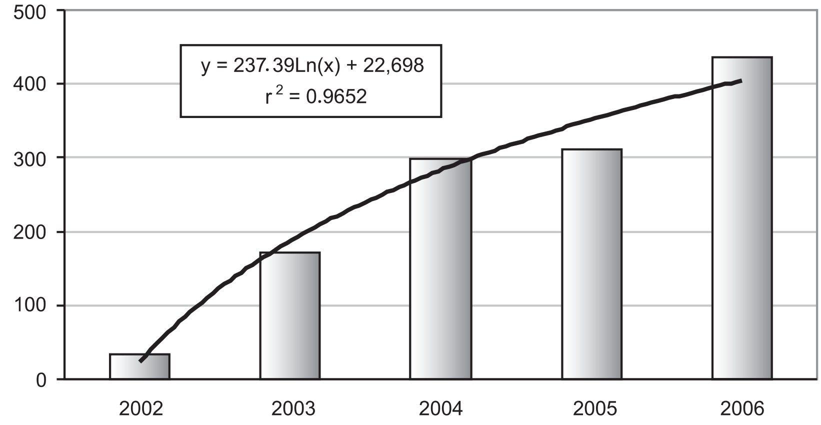

Figure 1. Number of clinical cardiac magnetic resonance examinations from 2002 (half year) to 2006. The curve of best fit is logarithmic (equation and r^2 are shown on the graph).

ic imaging of the heart and/or great arteries in 753 (75%), functional imaging of the left and right ventricle in 989 (99%), delayed-enhanced imaging for assessment of viability in 410 (41%), contrast-enhanced angiography of the great vessels in 422 (42%) and high-resolution imaging with the sequence used for coronary angiography[9] in 390 (39%) patients. In the great majority of patients who underwent imaging with the high-resolution coronary MR sequence, the primary reason for using this sequence was not delineation of the coronary artery integrity, but rather evaluation of the anatomy of the heart or great vessels with a high-resolution, free-breathing, bright-blood technique. Almost all patients (95%) had quantification of left ventricular function with cine imaging. Right ventricular quantitative analysis was performed in 23% of the patient cohort. In general, right ventricular quantitative analysis was performed when there was known or suspected right ventricular pathology, which explains why the abnormal findings regarding the right heart were proportionately more common than for the left heart. Table 2 summarizes the left and right ventricular measurements for the study cohort.

Non-cardiac findings occurred in roughly 10% of the studies. The incidence of non-cardiac findings depending on the organ/system involved is presented in Figure 2. In many patients, non-cardiac findings were related to the primary cardiac diagnosis (e.g. pleural effusion in a patient with congestive heart failure), while in several instances the findings were entirely incidental (e.g. liver cysts or hemangiomas).

The occurrence of complications during CMR imaging was extremely rare (0.1%) in our first 1000 cases. The most serious event occurred in one pediatric patient, who had seizure activity following contrast administration for evaluation of a large cardiac mass. Up to 90% of children with cardiac rhabdomyomas, the most common cardiac tumor in infants, have tuberous sclerosis commonly presenting with seizures.[10] Thus, the seizure activity in this patient may not have been related to the CMR examination *per se*. In any case the patient was quickly stabilized and had no further sequelae. One patient complained of a burning sensation at the site of a titanium plate in the cervical spine, leading to early termination of the examination. Finally, one other examination was terminated early because of severe claustrophobia.

In 48 examinations (~5%) the image quality was deemed suboptimal, although most of these studies

Table 2. Quantitation of left and right ventricular functional parameters in the study cohort.

Functional left ventricular parameter (962 patients):	
End-diastolic volume (ml)	167 ± 81
End-diastolic volume index (ml/m^2)	92 ± 39
End-systolic volume (ml)	76 ± 71
End-systolic volume index (ml/m^2)	41 ± 37
Ejection fraction	60 ± 16
Myocardial mass	120 ± 50
Myocardial mass index	67 ± 24
Functional right ventricular parameter (228 patients):	
End-diastolic volume (ml)	175 ± 88
End-diastolic volume index (ml/m^2)	106 ± 44
End-systolic volume (ml)	80 ± 51
End-systolic volume index (ml/m^2)	48 ± 28
Ejection fraction	56 ± 11
Myocardial mass	57 ± 29
Myocardial mass index	35 ± 14

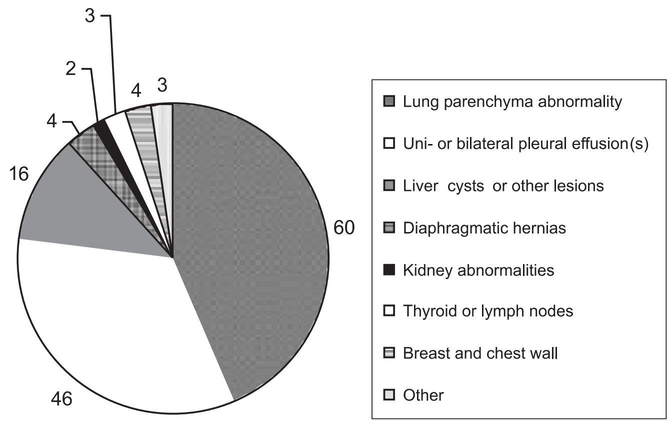

Figure 2. Non-cardiovascular findings encountered in the 1000 cardiac magnetic resonance examinations.

were adequate for clinical evaluation. Atrial fibrillation with wide heart rate variability and frequent supraventricular or ventricular ectopy were the overwhelmingly most common causes. Arrhythmia is well known to adversely affect imaging gated to the ECG signal. There were also very few patients (N=3) with non-diagnostic studies due to severe degradation of image quality by susceptibility artifacts from thoracic stents/implants.

Discussion

Over the last few decades CMR has become a valuable diagnostic tool in cardiology. The spectrum of diseases in which CMR can offer additional information over and above conventional diagnostic methods is very broad, and spans from congenital to valvular to ischemic to myopathic heart diseases. In 2004 a consensus panel report on the clinical utility and indications of CMR was published simultaneously in the Journal of Cardiovascular Magnetic Resonance[11] and the European Heart Journal,[12] promptly followed by a categorization of criteria for CMR, by the American College of Cardiology Foundation Quality Strategic Directions Committee Appropriateness Criteria Working Group, in 2006.[13] Our practice of CMR has been in accordance with these recently published appropriateness criteria.

Compared to other noninvasive imaging modalities, CMR has multiple advantages. Firstly, it is entirely noninvasive, does not involve any exposure to ionizing radiation and the contrast media used (whenever necessary) are generally not nephrotoxic. The noninvasive nature of the examination makes it particularly appealing for pediatric or adolescent patients, especially those in need of repeat examinations over the course of the years. Patients with congenital heart diseases are the main representatives of this group, but also young individuals with myocarditis and cardiomyopathy, for whom close follow-up is indicated to access prognosis and guide therapy. CMR also offers exquisite resolution (spatial, contrast and temporal) that can identify minute structures or tissues with minimally different consistency. For cardiac functional studies CMR has been shown to provide highly accurate measurements of left and right ventricular volumes, ejection fraction and mass, and CMR is currently considered as the standard reference for assessment of these quantities. Others[14-16] and we ourselves[17] have shown an extremely high reproducibility of measurements, which renders this technique appropriate for serial measurements before and after application of specific therapies.

CMR is not free of limitations. Patients with claustrophobia are not good candidates for CMR examination. We have not recorded data on how many studies were not performed because of severe claustrophobia and were either cancelled or rescheduled to be performed under intravenous sedation. However, it is our opinion that in well-informed individuals the number of subjects that cannot freely undergo a CMR examination is less than 2%. Data in the literature suggest that this number may be as high as 5%,[18,19] but appropriate environment, detailed description of the examination and coaching of the patient, headphone music, and convenient positioning, are very helpful to keep the patient involved during the study and allow for a diagnostic study.

Patients with pacemakers and defibrillators are not candidates for CMR. Deaths have been reported in patients who had pacemakers or pacemaker wires and who inadvertently had an MRI examination.[20] Recent data suggest that for selected pacemaker patients it may be safe to perform an MRI study,[21] but regulatory bodies[22] have been rather conservative regarding this, as are we, and we still consider the presence of pacemaker, defibrillator or pacing leads as absolute contraindications for CMR.

Among the first 1000 examinations, the number of coronary angiography CMR examinations that we performed to assess the presence of coronary artery disease was small. The current role of CMR coronary artery imaging is rather limited and mostly for imaging of the origin of the coronary arteries. Our group has recently examined the sensitivity and specificity of the CMR examination for detection of significant coronary artery disease and we have found good sensitivity with intermediate specificity.[23] For most patients with suspicion of coronary atherosclerosis CMR is not appropriate, as the positive examination does not obviate the need for further testing, while a negative examination only applies to the segments of the coronary arteries that are well visualized.

Applications of CMR that have recently gained acceptance and appear to be promising for the evaluation of suspected coronary artery disease include stress testing, both with inotropic stimulation (dobutamine CMR) and with vasodilation (adenosine-perfusion CMR). These applications are not performed anywhere in Greece at the present time. The reasons are mostly practical. Dobutamine CMR, for example, carries a small risk of complications (arrhythmia, myocardial ischemia or infarction, nausea/vomiting), requires the presence of a cardiologist on-site and a nurse practitioner, and is a rather lengthy examination. Perfusion CMR, on the other hand, still has questionable reproducibility and is a method under development.

In our country there are less than 10 centers in private or public health care systems that perform CMR. Most of these sites are located in the greater Athens region. As the clinical cardiologists appreciate the value of CMR, the application of this technique is expected to increase. In our center there has been a steady increase of cases over the last few years, paralleled by an increase in the number of referring physicians. We strongly believe that two components are necessary for further development. The first is maintenance of a high quality of examinations and interpretations that will generate confidence in the examination. The second is education of the cardiology community about the diagnostic value of CMR. Our center has been dedicated to advancing on both these fronts. CMR skeptics propose that the relatively high cost of the examination will limit its utilization. Indeed, the cost of a CMR examination for out-of-pocket payers in our institution is three times the cost of a transthoracic echocardiogram, approximately 1.4 times the cost of nuclear scintigram and approximately 0.4 times the cost of a diagnostic cardiac catheterization. In assessing the value of a diagnostic technique, one has to take into account the cost-effectiveness rather than the cost alone. We believe that the value of a CMR examination in selected patients (as described above) far outweighs the cost. Although no cost-effectiveness data on CMR have been published to our knowledge, public and private insurance agents are routinely reimbursing CMR studies in the USA and western Europe, corroborating our view of CMR's cost-effectiveness.

Conclusions

CMR is a rapidly evolving noninvasive diagnostic imaging modality whose clinical utilization is steadily increasing in Greece. Our center's experience from the first 1000 cases demonstrates the areas of established clinical value and highlights the perspectives for future development.

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