

Cardiac Intervention

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Technical Requirements

As a subset of general interventional MRI, MR-based cardiac interventions require specific hardware and software technology in order to be effective and safe. While many of these have already been developed and continue to improve, others have yet to reach a level adequate for human applications. The following is a broad list of these requirements:

1. Access to patient during procedure

Until very recently, "interventional" scanners compromised field strength, gradient performance and in some cases radio-frequency (rf) coil design in order to provide better patient access. Early designs were resistive low field strength (0.1-0.3T) systems or low field (0.5T) superconducting systems with limited signal-to-noise (SNR). Applications were generally limited to surgical interventional imaging using non-real time sequences for identification of and positioning devices within non-cardiac tumors. In that cardiac interventions require use of rapid and real-time sequences for freezing cardiac motion and tracking intravascular devices early research was performed on conventional 1.5T superconducting systems. With bore lengths that could exceed 2.3m, and bore diameters of only 0.5m, manipulation of catheters near the magnet iso-center was awkward at best. This situation has changed dramatically with the most recent magnet designs providing 0.7m bore diameter and a overall length of only 1.25m while maintaining gradient performance and flexible rf coil design. It is on these systems that the first-in-man MR-based procedures will likely occur.

2. Adequate display of images and information to the operator

MR-based diagnostic or interventional procedures are interactive dynamic studies in which by definition the patient may be hemodynamically compromised. Therefore there is a requirement for significant and diverse information that must be available in real-time to the operator. Data includes real-time images, previously acquired reference or pre-procedural images, images having undergone some form of processing such as coil specific color coding, integration of multi-plane images into 3D display format, surface rendering of multislice or 3D data, physiological data including ECG, invasive blood pressures, oxygen saturation levels and respiration rate. Waveforms and alphanumeric data have less demanding display requirements than images that must be presented without loss of resolution on an MR-compatible display system within a significant magnetic field near the scanner. To date two approaches have been employed. MR-compatible flat panel monitors have been commercially available for some time. As with all displays and electronic equipment located within the rf shielded scanner room, the display must neither

be effected by the operation of the scanner nor can it produce noise that would degrade MR image quality. The second display device is that of the LCD projection system. Images produced using this device may be projected on various opaque and translucent surfaces with the advantage that adjusting the display size is a simple matter. A desired characteristic of any display system is the presence of significant definable "real estate" such that there is sufficient space to display the required information and that the display may be reconfigured between image, waveform and alpha-numeric data.

3. Image reconstruction hardware

In terms of image display, latency period may be defined as the time delay from when an image is acquired until it is reconstructed and displayed to the operator. In manipulating intravascular devices under real-time image guidance, even a small latency period makes accurate positioning impossible. Current commercial scanners are capable of reconstructing and displaying images at relatively low frame rates (5-8 frames per second). Because of this, many institutions have developed custom built computer systems capable of high speed reconstruction and processing of images by bypassing commercial reconstruction hardware. As interventional procedures become more widespread it is likely that manufacturers will upgrade their hardware to deal with the more computationally demanding real-time imaging.

4. Adequate physiological monitoring

Physiological monitoring equipment currently used in cardiac catheterization laboratories are the result of decades of evolution and refinement. Not only are systems able to monitor and record a wide range of invasive and non-invasive vital signs, but based on these data they are capable of calculating such parameters as valve area, trans-valvular pressure gradients and many others. Additionally the systems are used to record and track drug administration and device utilization. There are two options available for MR-compatible physiological monitoring. That provided by the MR-equipment manufacturer and 3rd party equipment vendors. In both cases devices are limited to monitoring, but not recording, non-invasive vital signs such as ECG, cuff blood pressure and pulse oximetry. A challenge unique to the MR-environment is the production of artifacts on physiological waveforms. It is best understood for ECG artifacts but may also be present on other physiological waveforms. ECG signals are corrupted by two major artifacts. Time varying gradients induce eddy currents within tissue which result in non-cardiac electrical signals which are picked-up by the ECG electrodes. Pulsatile blood flow through the aorta results in distortion of the ECG (primarily in the region of the T-wave) due to the magnetohydrodynamic also known as the Hall effect. While there has been success in reducing or eliminating the gradient artifacts using a number of methods, the pulsatile blood-flow artifacts are much more challenging and as yet has not been eliminated. It is possible that some of the more sophisticated cath-lab systems may be made MR-compatible. It is clear that the current limited function MR-compatible physiological monitoring systems are inadequate for patient procedures.

5. Flexible real-time imaging interface

The goal of a real-time software interface is to permit a smooth uninterrupted acquisition of real-time images with various contrast characteristics at arbitrary plane orientations. One of many advantages of MR-based interventions compared with their x-ray based counterparts is the ability to take advantage of the nearly unlimited soft tissue contrast available with MRI. A real-time interface can provide interactive on-the-fly control of parameters including plane orientation, spatial resolution, field-of view, k-space trajectory, image contrast such as SSFP, spin echo, FLASH, T1 or T2 weighting, application of inversion or saturation pre-pulses for use with contrast agent administration. Further, display control may include selection of multiple orthogonal image planes, different color coding for intravascular rf coils, utilization of small rf coils positioned on intravascular devices in order to automatically match the position of the acquired image plane with the device being manipulated, and image processing or surface rendering of data prior to display. It is important to maintain an uninterrupted stream of image data during the procedure while at the same time being able to provide “on-demand” changes in contrast. There has been significant advancement in this interface particularly as the reconstruction hardware has provided the ability to make use of computationally more demanding image reconstruction and display schemes.

6. Family of MR-compatible intravascular devices

Whether the procedure is diagnostic or therapeutic, cardiovascular interventions require a diverse family of intravascular devices. Devices have been developed to have specific mechanical characteristics that improve their function including torque control (torque of the distal end of the device results in similar torque transmitted to the proximal end), pushability (sufficient device stiffness to permit advancing a device along a curvilinear path), anti-kink performance (resistance to kinking when the device is manipulated into a sharp angle) as well as others. These properties have primarily been achieved by incorporation of metal braid within the wall of the catheter or use of coated metal in the case of guide wires. Depending on the diameter and composition these wires may produce a substantial artifact on MR images, additionally, as conducting wires they have the potential to produce “hot spots” during image acquisition. In order to produce MR-compatible devices a number of non-metallic, fully composite catheters and guidewires have been developed. Although MR-safe and lacking image artifacts, these composite devices, if left unmodified are essentially invisible during imaging. Therefore a number of active and passive approaches have been employed in order to achieve device visibility. Passive approaches include filling the catheter body with dilute gadolinium (to produce positive signal enhancement) or incorporating bands of Dysprosium on either the catheter or guidewire to produce negative contrast. Active approaches include either incorporation of a small receiver coil(s) into the device which when connected to a coil channel may be visualized as a region of bright signal. Another approach includes incorporation of a self-resonating coil (not connected to a receiver channel) or converting other devices such as metal stents and vena cava filters

into resonant circuits that also produce enhanced local signal. While there are a number of well functioning MR-compatible devices under development, substantial additional resources need to be applied in order for any of these devices to become FDA approved for human use. Until such time, human studies will have to be performed with the limited family of MR-compatible/FDA approved devices, which in most cases are mechanically inferior to the best available metal-based devices.