Introduction  Modern real-time MRI (RT-MRI) involves the continuous acquisition, reconstruction, and display of images with 1) minimal acquisition time per image (usually < 100 ms) and 2) minimal acquisition-to-display latency (usually < 300 ms). It allows one to capture dynamic processes as they happen without the need for gating, breath-holding, or patient cooperation [1, 2], and has been made possible by the availability of fast-switching gradients, parallel imaging, spiral and echo-planar acquisitions, and improvements in reconstruction speed.

Applications include the rapid localization of scan-planes [3], coronary imaging [4], myocardial function and strain [5, 6], and cardiac flow [7]. These are often limited by SNR at 1.5T, which motivates development at 3T. The 3T platform provides advantages such as increased polarization, longer T1 times, and larger fat-water differences, along with challenges including increased off-resonance, increased RF heating, and RF transmit non-uniformity.

Coronary Imaging  is particularly SNR- and CNR-limited at 1.5T [4]. High-resolution 3T RT-MRI coronary imaging using water-selective spiral gradient-echo imaging was recently demonstrated and compared with an comparable approach at 1.5T [8] (1.5 mm in-plane resolution and 120 ms temporal resolution). The doubling of the fat-water frequency difference at 3T (440 Hz) allowed for the design of an exceptionally short spectral-spatial pulse (2.8 ms). Excellent fat suppression and motion artifact suppression was observed in all subjects (see Fig. 1). RT-MRI exhibited a 53% improvement in blood SNR efficiency and a 232% improvement in blood-myocardium CNR efficiency (without contrast agents) compared to 1.5.

Myocardial Function  can be assessed using conventional RT-MRI with wall-motion analysis [5] or more completely using real-time tagging or real-time strain encoding [6]. Because myocardial T1 is longer at higher field strengths, tag-based methods (which encode information in the longitudinal magnetization of spins) experience substantial improvements in SNR and possible encoding times at 3T.

Flow-based Contrast  can be achieved using gradient-echo phase contrast at 3 Tesla [9] (see Fig. 2a). While no study has directly compared 1.5T and 3T linear improvements in SNR are expected in regions of flow because flowing spins will experience less partial-saturation than static spins. Recent developments in balanced steady-state free precession (bSSFP) phase contrast using a single steady-state [10] also have the potential to further improve velocity SNR in real-time phase contrast.

Flow can also be used to generate black-blood contrast using spatial pre-saturation pulses [11, 12] (see Fig. 2b). Again, while no study has directly compared suppression at 1.5T and 3T, greater than linear improvements in blood-myocardium CNR are expected because of increased blood T1.

Current RT-MRI Product Sequences  are geared towards localization and the evaluation of ventricular func-
Figure 3: 3T RT-MRI user interface and image quality (Philips product sequence). Imaging parameters: balanced SSFP with rate-2 SENSE, flip angle 40°, resolution 3×3×8 mm³, 6-12 images/s. Similar sequences/interfaces are available from all three major vendors.

tion in patients with arrhythmia or who are otherwise uncooperative. The sequence of choice is balanced steady-state free precession (bSSFP, alternatively known as True-FISP, FIESTA, or Balanced-FFE), because of its high SNR efficiency, accelerated using parallel imaging [13, 14].

Key features of these systems (produced by all three major vendors) are:

- **Image Quality/Speed:** Images possess high blood-myocardium contrast (native to bSSFP), with 3×3×8 mm³ spatial resolution acquired at 6-18 frames per second. Parallel imaging with reduction factors of 2 to 4 are achieved with modern 8- to 32-channel cardiac arrays [13, 14].

- **Intuitive User Interfaces:** Graphical user interfaces are essential for the task of rapid localization (see Fig. 3), and include tools for prescribing perpendicular cuts from existing views, for placing and revisiting bookmarks, and for performing simple image analysis/processing tasks.

- **Artifact Management:** The primary source of artifact is off-resonance, and it is mitigated using a bSSFP TR of 3.2 - 3.6 ms and localized shimming [15]. Some products sequences include an operator control to fine-tune the center frequency (or bSSFP phase-cycling increment) so that this artifact can be moved outside of a region of interest.

**Summary.** The role of RT-MRI is growing to include localization, high-resolution imaging, flow imaging, functional imaging including myocardial mechanics, and interventional imaging (not discussed because most interventional work today is done at 1.5T). RT-MRI at 3T, in many cases, requires redesigning pulse sequences to deal with the increased off-resonance (fat-water chemical shift and susceptibility), increased RF heating, and RF field variations. There are many opportunities for basic and applied research in the area of high-field RT-MRI.

**References**


