ISMRM 2011 Sunrise Course
Fast and Furious: the New Era of Rapid Imaging
Fast Body imaging

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Continued development of gradient hardware, improved RF technology including increased coil counts, and other technical improvements in MR hardware and applications have led to reductions in scan time, increases in SNR, and improved spatial and temporal resolution that, in turn, have contributed to tremendous improvements in body MR imaging over the past decade. Further, sequence innovations have led to improved image quality and increased diagnostic information with more robust and reliable exams that now rival and often surpass CT scanning for routine abdominal and pelvic imaging. In addition to these improvements in acquisition speed and image quality, recent concerns over radiation exposure and contrast induced nephropathy from iodinated contrast exposure have also led to greater demand for MRI body imaging. Not only has MRI evolved into a better "CT-like" exam but it also offers many additional contrast mechanisms such as diffusion weighted imaging, quantitative biomarkers of fat and iron, as well as visualization of edema through T2-weighted imaging. Despite the numerous advances in image quality, there are multiple challenges that remain that will fuel the need for continued improvements in body MRI and provide new opportunities for both diagnosis and therapy monitoring. In this combined session presented jointly by a clinician and an MR physicist, we will expand on four of many examples of current clinical applications of body MRI including the clinical motivation and challenges. Each topic will be addressed with possible technical solutions and current cutting edge research that is being performed in these areas. The four topics include:

1. Rapid T1-weighted dynamic contrast enhanced (DCE) imaging
2. Diffusion weighted imaging in the abdomen and pelvis
3. Quantitative biomarkers of fat and iron
4. Advanced hepatobiliary imaging with new hepatobiliary contrast agents

1. Rapid T1-weighted dynamic contrast enhanced (DCE) imaging

Current clinical practices and needs

The current mainstay of diagnosis and evaluation of abnormalities in the abdomen and pelvis relies on breath held dynamic contrast enhanced T1-weighted imaging (DCE). Typically, multiple sets of breath held data are acquired during the passage of a gadolinium based contrast agent. A pre-contrast T1-weighted image followed by a peak arterial phase, a late arterial phase, a portal venous phase, and 2-5 minute delayed T1-weighted images are acquired. Scan time is typically 20-25 seconds for each acquisition using a 3D spoiled gradient echo technique with chemically selective partial inversion recovery for fat suppression. These methods are well established and provide excellent qualitative characterization of abnormalities such as liver masses, renal masses, or pancreatic masses, etc. The enhancement patterns of these abnormalities in combination with other contrast mechanisms such as T2 and diffusion weighted imaging are critical for establishing diagnoses. However, these methods are limited by their relatively low temporal and spatial resolution. In addition, the ability to time the bolus accurately and reproducibility between exams performed on different dates is essential to determine whether intervening therapy has led to a meaningful change. The use of time resolved contrast enhanced imaging with high temporal resolution avoids mis-timing because multiple time frames are acquired.

In recent years, the advent of anti-angiogenic agents for the treatment of a variety of tumors has put new demands on DCE imaging. Previously the assessment of a tumor response to chemotherapy was measured using the RESIST criteria, which are based only on the size of a tumor. Anti-angiogenic agents act on tumors by interrupting the blood supply at the microcirculatory level and may result in no change in tumor size, even in tumors that respond well to therapy. Changes in the perfusion (i.e., local blood flow) may be dramatic when anti-angiogenic agents are effective. Therefore quantitative biomarkers for accurate characterization of perfusion are urgently needed. Such a biomarker would require a combination of high spatial resolution, high temporal resolution, and high SNR with complete volumetric coverage of a large area of the abdomen and/or pelvis. Obviously these are competing needs that require technical improvements.

Emerging techniques

There are numerous approaches that can be taken to address the competing needs of higher spatial resolution, higher temporal resolution, volumetric coverage, and high SNR performance. Researchers have been exploring novel k-space trajectories ranging from innovative phase-encode ordering for Cartesian acquisitions to 3D true radial approaches. In some cases, these new k-space trajectories are enabled by non-traditional approaches to fat suppression. As always, parallel imaging is a powerful weapon in the fast-imaging arsenal. Finally, some work has explored the use of constrained reconstruction methods. Examples of specific approaches and their promising results will be described.

2. Diffusion weighted imaging in the abdomen and whole body DWI

Current clinical practices and needs

Diffusion weighted imaging has experienced increasing use in abdominal and pelvic applications during the last five years, primarily for the detection of lesions (example: metastatic disease in the liver) as well as ADC characterization for treatment response.

Despite the great promise and the current utility of diffusion weighted imaging, image quality is currently inadequate for many applications. For example, the use of DWI for screening for metastatic disease within the liver is currently plagued by inconsistent image quality. This may be due to a combination of factors such as motion and/or magnetic susceptibility but regardless, the inability to reliably obtain volumetric diffusion-weighted coverage of the liver limits this method for screening for metastatic disease.

Emerging techniques

Diffusion weighted imaging in the abdomen and pelvis is an area of active investigation. As outlined above, there is a clear need to improve routine image quality. Researchers are taking a variety of approaches to achieve this goal, focusing on different technical challenges related to DWI imaging. Some work is focused on adapting EPI distortion-correction methods from brain to body applications. Other efforts are focused on innovative new k-space trajectories or acquisition schemes to reduce distortion and possibly enable higher spatial resolution acquisitions. Yet other researchers are investigating the impact of cardiac motion on DWI image quality and exploring methods to compensate. Finally, at least one group is exploring new contrast mechanisms that maintain the desirable aspects of DWI, without some of the image quality challenges. Specific examples of a range of innovative work and representative results will be described.

3. Quantitative biomarkers in fat and iron

Current clinical practices and needs

The current epidemics of obesity and diabetes have led to a surge in the metabolic syndrome, a feature of which includes non–alcoholic fatty liver disease (NAFLD). There are an estimated 20-80 million Americans currently afflicted by this disease which is the most common cause of chronic liver disease. Unfortunately, current imaging methods are able to qualitatively detect the presence of fat within the liver but there are no non-invasive quantitative biomarkers. Such quantitative biomarkers are urgently needed for diagnosis of fatty liver disease through the accurate threshold based detection of intracellular fat (steatosis). Further there are numerous confounding factors such as T1, T2*, spectral complexity of fat, eddy currents, etc. which render current dual echo in- and opposed phased imaging inadequate for quantification of fat. Such non-invasive quantitative imaging methods would need to be rapid to enable economical screening and monitoring of appropriate populations.

Genetic hemochromatosis and various anemias that result in iron overload (hemosiderosis) are of great clinical importance. The degree of iron in the liver is a known risk factor for the development of cirrhosis and hepatocellular carcinoma. Liver iron concentration is also an excellent indicator of total iron body stores, and it is important to assess total body iron as an indirect marker of cardiac iron overload - cardiac iron overload is one of the potentially fatal complication of this condition. Therefore accurate assessment of iron within the liver, pancreas, spleen and bone marrow are of great clinical significance. Prior work using T2* and T2-weighted imaging techniques have shown strong correlation to iron concentrations. However, these techniques may suffer from long scan times (R2 mapping methods) or may be confounded by external susceptibility and from the presence of fat (R2* methods). These confounding factors may lead to platform dependence and protocol dependence, diminishing their impact as reliable and robust biomarkers of iron concentration. Further, they are also impacted by the presence of fat which confounds the ability of multi-echo T2*-weighted methods to accurately quantify iron. Therefore, improvements in T2- and T2*-weighted methods are urgently needed in order to provide a platform and protocol independent quantitative biomarker of liver iron.

Emerging techniques

Multiple solutions have been proposed for accurate quantification of fat. These methods are based on one of two major imaging classes. The first is magnitude based MRI and the second is complex based MRI. These techniques provide estimates of the proton density fat fraction, which is an inherent property of tissue. In order to obtain proton density fat fraction, it is essential to remove all known confounding factors including T1, T2*, spectral modeling, eddy currents among others. In this talk, we will review how these approaches are able to avoid or remove these confounding factors in order to provide a measure of the proton density fat fraction. Recent examples in phantoms, animals, and human studies will be reviewed.

More recent work on improved measurement of R2*, free from confounding factors such as macroscopic external susceptibility, the effect of spatial resolution and the confounding impact of the co-existing presence of fat in the liver will also be discussed using chemical shift-based water-fat separation techniques that provide simultaneous estimation of T2*.

4. Advanced hepatobiliary imaging

Current clinical practices and needs

In July 2008, gadoxetate disodium (Gd-EOB-DTPA, Eovist, Bayer Healthcare, Wayne, NJ) was approved by the FDA and has become a widely used hepatobiliary gadolinium contrast agent for liver imaging. Eovist has an approximately 50% hepatic uptake and subsequent biliary secretion at approximately 20 minutes making this a very useful agent for performing hepatobiliary imaging. Gadobenate dimeglumine (Multihance, Gd-BOPTA, Bracco Pharmaceuticals, Princeton, NJ) also has 5% hepatobiliary excretion and can also be used for this purpose. Specific applications include detection of metastatic disease (surrounding liver appears bright, mets appear dark), characterization of HCC, hepatic adenomas and FNH, as well as functional and anatomic biliary imaging through high resolution T1-weighted MR cholangiography.

Unlike dynamic contrast enhanced T1-weighted imaging, during the hepatobiliary phase, the contrast is in a relative pseudo-steady-state where the contrast pharmacokinetics are relatively slow. This offers an opportunity (perhaps 5 minutes) for very high spatial resolution imaging. In addition, because of the relatively high concentration of gadolinium in the liver, there is a large amount of SNR, and in combination with the increased available scan time, very high spatial resolution images of the liver and bile ducts should be possible. This represents an opportunity to exceed CT scanning for very high resolution imaging of the bile ducts. Very high spatial resolution of the bile ducts is necessary for applications such as subtle biliary disease (primary sclerosing cholangitis) as well as the identification of variant biliary anatomy for living related liver donors. Currently, this is performed with CT cholangiography, which is limited by the inability to do multiple time points during the excretion of contrast and the limitation of the need for ionizing radiation. Overall, an optimized, free breathing very high spatial resolution T1-weighted imaging in less than 5 minutes is needed to fully exploit the use of these new hepatobiliary gadolinium based contrast agents.

Emerging techniques

Recent work has explored the use of navigators with contrast-enhanced T1 weighted acquisitions to achieve high spatial resolution while capturing the pseudo-steady-state hepatobiliary-phase contrast. Imaging parameters must be adjusted compared to a typical arterial-phase acquisition to maximize SNR and CNR for the bile ducts, liver, and liver lesions.

Summary

At the end of this session, it is our hope that we have identified several areas of current interest in abdominal imaging, namely, dynamic contrast enhanced perfusion imaging, diffusion weighted imaging, new methods for quantitative biomarkers of iron and fat, as well as advanced hepatobiliary imaging. These are but many examples of emerging clinical applications and how emerging technologies can be translated into important new clinical applications. Further, it is our hope that we have demonstrated the need for close interactions between clinicians and physicists in order to understand the clinical needs and translate emerging technologies into important new applications that will improve the safety and efficacy of advanced imaging techniques in patients.