Diffusion Weighted MR Imaging of the Extrahepatic Abdomen and Pelvis

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Introduction

Diffusion-weighted imaging (DWI) provides a new contrast mechanism for evaluation of the abdominal, and pelvis. By imaging microscopic motion of water molecules DWI yields new qualitative and quantitative information about tumors that can be used to improve tumor detection, characterize some tumors, and monitor and predict response to treatment. DWI techniques provide a host of new tools for the body imager including magnitude DW images, ADC maps with quantitative analysis, and volumetric display of data including whole body diffusion with background suppression (DWIBS).

For extrahepatic abdominal MR imaging DWI is critically essential for depicting benign and malignant diseases of the bowel, peritoneum, omentum, solid organs, and osseous structures. The complexity of these multiple organ systems can challenge even the best abdominal imager when confronted with hundreds of images for a single study. Diffusion-weighted images provides an essential tool that will simplify the approach to these complex studies and will improve the sensitivity and accuracy of image interpretation. In our practice DWI

is likely the single most important advance in abdominal MR imaging in the past decade.

Technique

Abdominal DWI can be performed on commercially available high field MR systems. Most vendors currently utilize a single shot spin-echo EPI pulse sequence for DW imaging. DW imaging can be performed as a breath hold acquisition or as a breathing averaged acquisition with multiple excitations. The later may be acquired as a free breathing or respiratory triggered acquisition. In the DW pulse sequence paired diffusion sensitizing gradients are centered on either side of the 180 degree refocusing pulse. In the absence of motion water molecules will acquire phase information from the first diffusion gradient that will be refocused by the second diffusion gradient with no net change in signal. However, with moving water molecules the situation is different. The water molecules will accumulate phase information from the first gradient that will not be completely refocused by the 2^{nd} diffusion gradient due to movement of the water molecule producing a loss of signal. The paired diffusion gradients will thus detect water motion as areas of signal loss. Tumors with a higher cellular density possess more cell membranes per unit volume which restricts mobility of water molecules and diffusion. These tumors will exhibit restricted diffusion and corresponding high signal on DW imaging.

The sensitivity of the DWI sequence to water motion can be varied by changing the b-value which changes the amplitude of the paired bipolar diffusion

sensitizing gradients. One typically acquires at least two b-values of 0 s/mm2 combined with a second intermediate to a high b-value of 400 s/mm^2 to 1000 s/mm^2. Acquiring additional b-values will improve the accuracy of the quantitative data obtained from DW imaging. Higher b-values result in more diffusion weighting with better background suppression, at the expense of reduced signal and increasing artifacts.

Diffusion experiments can be independently made in the phase, frequency, or slice directions by applying the diffusion gradient in the selected direction. One may also combine the diffusion signal from all three directions to create a summed image known as an index or magnitude diffusion image. A summed diffusion image loses its directional information but will improve scanning efficiency allowing for shorter breath hold scan times while maintaining signal-noise-ratio.

Early DWI pulse sequences were quite limited as they were optimized for brain imaging. Newer Diffusion sequences which are currently available provide more flexibility in parameter selection and are considerably more robust. One may select 40 or move different b-values and one can explicitly select the NEX for each b value to improve efficiency of scanning. Different types of fat suppression are available for optimal fat suppression in different anatomic areas. The following is a typical protocol for breath-hold abdominal DWI used for anatomic imaging.

- Single Shot Spin-Echo EPI
- Phased array surface coil
- B-value 0, 500, 800 s/mm^2
- Slice thickness 7 mm, 1 mm interslice gap
- FOV 320 – 400 cm
- TR 3000
- TE 58 (min)
- Matrix 192 x 224
- SPIR fat suppression
- 24 slices
- 2-3 nex
- Direction of motion probing gradients: phase, frequency, slice
- Pure of Clear to improve image homogeneity
- Acceleration factor 2
- Time: 24 sec breath-hold

Whole body DW imaging is performed with multiple stacks of axial DW acquisitions covering large anatomic areas that may include head, neck, chest, abdomen, pelvis and lower extremities. The axial plane is chosen to minimize image distortion. A three to five station whole body DWI protocol can be prescribed with overlap between the stations. Some MR systems allow for whole body imaging with multiple surface coils. On other systems whole body DWI will require imaging with the integrated large body coil. Once the multiple axial DWI

stacks are prescribed and pre scanned automatic table movement between stations facilitates scanning and data acquisition.

Clinical Applications

Gastrointestinal Tract

Gastrointestinal cancers as well as infectious and inflammatory diseases show restricted diffusion. High b-value DWI shows high sensitivity and specificity for detecting colorectal cancers. Measurement of tumor ADC value can predict which tumors will respond to chemotherapy and radiation therapy. Following effective therapy cancer show an interval increase in ADC value which can be measured as appreciated as a decrease in tumor signal on magnitude DWI images. Similar improved depiction of esophageal and gastric cancers is also noted with DWI MR imaging.

For infectious and inflammatory gastrointestinal disease, DWI can provide improvements in detection of the abnormal bowel segment. Restriction of diffusion is a marker of active inflammation. For patients with Crohn's disease sites of active inflammation will show diffusion restriction in the thickened segments of bowel. With effective therapy these segments will show resolution of diffusion restriction on follow up MR examinations. Chronic fibrotic strictures do not show diffusion restriction. By combining the information from DWI with conventional MR imaging one can more accurately determine the disease extent and activity.

Peritoneum

Peritoneal carcinomatosis and isolated peritoneal tumors can be challenging to detect and are often missed on CT and PET CT. Peritoneal cancers show restricted diffusion. Due to the normal suppression of background tissues, ascites, and bowel contents, even small peritoneal metastases were conspicuous on DWI obtained with an intermediate b-value. A combination of DWI and delayed gadolinium-enhanced imaging provides optimal peritoneal tumor depiction. In our experience these two contrast mechanisms provide complementary and confirmatory information. Often thin sheets or tumor in the subphrenic areas are easier to detect on the delayed gadolinium-enhanced images. Mesenteric and serosal tumor in the abdomen and pelvis are best depicted on the DWI images due to the inherent suppression of bowel contents and ascites.

DWI and gadolinium-enhanced imaging effectively detects peritoneal metastases in patients with many primary malignancies including cancers of the ovary, gastrointestinal tract, pancreas, and appendix. In patients being considered for surgical cytoreduction and HIPEC DWI and gadolinium-enhanced MRI can accurately predict the peritoneal cancer index (PCI) a measurement of the extent and distribution of intraperitoneal tumor.

Solid Organs

Pancreas: Pancreatic cancer typically shows lower mean ADC value than normal pancreatic parenchyma and benign pancreatic lesions. DWI may also be

useful to characterize pancreatic cystic lesions. Cystic pancreatic neoplasm, abscesses show lower ADC values than simple pancreatic cysts and pseudocyts. Due to overlap of ADC values DWI may not be able to clearly separate solid pancreatic cancers from some solid inflammatory lesions. Mass forming pancreatitis may show a similar low ADC value to to its dense fibrosis making it difficult to distinguish from pancreatic cancer.

Kidneys: Focal renal parenchymal diseases including segmental ischemia, pyelonephritis, renal abscess, complex cysts, renal cell cancer, and transitional cell cancer show restricted diffusion. Patients with diffuse renal disease including acute and chronic renal failure, also show a decrease in the ADC values of both the renal cortex and medulla compared to normal kidneys.

Prostate: Diffusion-weighted imaging using a high b-value 1500 s/mm2 improves the detection and localization of peripheral zone prostate cancer. Prostate cancer shows a lower ADC value compared to benign prostate tissues. A Multiparametric approach combining the results of T2-weighted imaging, DWI, and DCE MRI provides optimal information for prostate cancer detection and staging. Measurement of ADC values may help to distinguish low risk from more aggressive high risk prostate cancers.

Uterus and Cervix: High b-value DWI can improve the detection and of endometrial cancer which shows significantly lower ADC value than benign

lesions and normal endometrium. (0.84 x 10^{-3} mm2/s vs. 1.58 x 10^{-3} mm2/s). There is a tendency for higher grade tumors to show more diffusion restriction Due to restriction of diffusion these tumors are hyperintense on magnitude DW images. Lesion characterization using DWI has been proposed but lacks an absolute cutoff between benign and malignant. The mean ADC value of an individual lesion will be affected by tumor grade and / or the presence of necrosis. High ADC values can be seen in well differentiated endometrial cancers and in necrotic poorly differentiated tumors Depth of myometrial invasion may also be better determined on high b-value DWI. Similar findings have been demonstrated for cervical cancers. For both uterine and cervical cancers DWI shows promise as a biomarker for treatment response with increasing ADC values following effective therapy.

Conclusions

Diffusion-weighted imaging is an essential element of abdominal and pelvic MR imaging. Providing both qualitative and quantitative information DWI can dramatically improve our accuracy in interpreting MR examinations. In our practice DWI provides the framework that brings some order to the complex world of the extrahepatic abdominal cavity.

References

1. Takahara T, Imai Y, Tomohiro Y, et al. Diffusion weighted whole body

imaging with background body signal suppression (DWIBS): Technical improvement using free breathing, STIR and High Resolution 3D display. Radiation Medicine 2004; 33:275-282.

2. Low RN, Barone RM. Combined Diffusion-Weighted and Gadolinium-Enhanced MR Imaging Can Accurately Predict the Peritoneal Cancer Index (PCI) Preoperatively in Patients Being Considered for Cytoreductive Surgical Procedures. J. Surgical Oncology. 2012;19:1394-1401.
3. Low RN, Barone RM, Lee MJ. Surveillance MR Imaging is superior to serum tumor markers for detecting early tumor recurrence in patients with appendiceal cancer treated with surgical cytoreduction and HIPEC. Ann Surg Oncol 2013;20:1074-1081.
4. Koh DM and Collins DJ, Diffusion-weighted MRI in the body: Applications and challenges in oncology. AJR 2007;188:1622-1635.
5. Tomoaki Ichikawa, Sukru Mehmet Erturk, Utarou Motosugi, Hironobu Sou, Hiroshi Iino, Tsutomu Araki, and Hideki Fujii. High-B-Value Diffusion-Weighted MRI in Colorectal Cancer. American Journal of Roentgenology 2006 187:1, 181-184.
6. Wang Y, Miller FH, Che ZE, et al. Diffusion-weighted MR imaging of solid and cystic lesions of the pancreas. Radiographics 2011;31: E47-E64.
7. Kim S, Naik M, Sigmusnd E, Taouli B. Diffusion-weightyed MR imaging of the kidneys and the urinary tract. Magn Reson Imaging

Clinics of North America, 2008;16:585-595.

8. Whittaker CS, Coady A, Culver L, et al. Diffusion-weighted MR imaging of female pelvic tumors: A pictorial review. 2009 RadioGraphics, 29,759-774.