Diffusion weighted imaging (DWI) on a MRgRT system

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Outline

• Introduction of current oncological applications of DWI
• The UCLA experience with implementing DWI using a 0.35T MRI on a MRgRT system
• Advantages and challenges of DWI acquired with current technology on MRgRT.
• Techniques that potentially can be used to achieve DWI with high spatial integrity and resolution, which is suitable for on-line RT applications.

Oncological application

• Improved tumor detection and diagnosis
• Tumor grading and prognosis
• Early prediction of normal tissue toxicity
• Early treatment response assessment and prediction

Target detection

- Metastases detection with whole body DWI

A. DWI (b=0)  B. DWI (b=400)  C. DWI (b=1000)  
D. ADC map  
E. FDG-PET  F. MIP of the inverted DWI (b=1000)  
G. Contrast enhanced T1w MRI  H. T2w MRI  


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Target detection

- DWI provided superior tumor detection capability than conventional T2W imaging for prostate cancer [1]

(A) T2W imaging  (B) the ADC map  (C) prostatectomy specimens. Note the higher cellular intensity in the cancer focus (black arrow).


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Tumor detection

- ADC value provided good differentiation of benign and malignant cervical lymph nodes [1]

Tumor grading and prognosis

- ADC values may help differentiate aggressive from low-grade prostate cancer [1,2]


Tumor grading and prognosis

- Low ADC is an indicator of high-grade and poor survival for malignant astrocytoma [1]


Treatment response prediction

- Successful treatment can lead to tumor necrosis → changes in cellular density
- DWI can detect changes earlier than tumor size changes [1,2]

Treatment response prediction

- Changes of ADC during treatment provided useful information about treatment response and patient survival [1-5]

Rectal patient with pathological complete response

A. Before therapy, mean tumor ADC = 0.87x10^-3 mm²/s
B. After therapy, mean tumor ADC = 1.44x10^-3 mm²/s.


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- Longitudinal DWI is feasible with the 0.35T ViewRay MRI.

CT simulation with GTV contour

MRI pre-Rx GTV

D. ADC change slope map throughout RT

MRI 23 months post-Rx confirm recurrence


- Treatment response prediction
  - Using features from all three time points provided the best AUC
  - Using single time point worked poorly for the treatment response prediction
  - SVM with T1-3 provided the best results (AUC=0.89 [0.73, 0.98])
UCLA experience

- DWI studies conducted using ViewRay system
- 0.35T MR-guided tri-cobalt 60 radiotherapy system
- Can be used as a standard MR scanner after disconnect MR from RT
- Capability of sequence programming using the Siemens IDEA platform

Advantages of implementing on-board DWI

- Advantages
  - Clinically practical to acquire additional/longitudinal imaging.
  - Easy arrangement logistically
  - DWI was acquired with same patient setup
  - Big bore system, patients could be imaged at treatment position

Challenges of implementing on-board DWI

- Challenges:
  - Conventional DW-ssEPI has geometric distortion and limited resolution
  - DP-TSE was developed for reduced distortion and improved geometric accuracy [1]

DP-TSE sequence at UCLA

• Diffusion module: Twice-refocused spin echo (TRSE) to reduce eddy currents.
• Readout module: TSE is robust to field inhomogeneity and susceptibility related artifact.

Advantages:
• Reduced geometric distortion, chemical shift artifacts, and susceptibility related artifacts
• Accurate and reproducible phantom ADC measurements

Limitations
• Longer scan time for multi-slice DP-TSE acquisition

Potential solutions for improved DWI

• To improve the spatial integrity
  • Perform distortion correction, e.g. field map-based distortion correction.
  • Switch to multi-shot technique, e.g. RESOLVE
  • Use other readout, e.g. DW-ssTSE
  • Reduced FOV

• To improve the resolution
  • Multi-shot technique.
  • Reduced FOV
Field map distortion correction

• One main source of distortion is B0 field inhomogeneity
• Field map can be measured using various methods (e.g., multi-echo GRE)
• This field map information is directly related with image pixel shift and can be used to correct for the distortion.

\[ x_1 = x \pm \frac{\delta B(x, y) T_x}{G_x}, \quad y_1 = y + \frac{\delta B(x, y) T_y}{G_y} \]


Field map distortion correction

• Advantages
  • Could reduce distortion caused by field inhomogeneity

• Disadvantages
  • Additional field map acquisition needed
  • Works mainly for B0 related distortion.
  • Relies on accurate measurements of field map.


Multi-shot technique

• Interleaved EPI [1]
• Readout segmented EPI [2,3]
• EPI-related distortion is governed mainly by slow traversal through k-space along phase-encoding direction.
• Segmented readout could mitigate corresponding distortion

Multi-shot technique

- **Advantages**
  - Reduced distortion and susceptibility related artifacts
  - Higher resolution

- **Disadvantages**
  - Longer scan time
  - Need to resolve shot-to-shot inconsistency (usually use navigator)


Use other readout module

- TSE, bSSFP, FLASH and other readout module have been implemented to reduce EPI related distortion. [1-6]
- Single-shot or more frequently multi-shot
- Various readout e.g. Cartesian, PROPELLER[2], spiral[3].


Reduced FOV

- Total duration of the actual data sampling during EPI readout.
- Reduced echo train length.
  - Inner volume imaging (IVI) [1,2]
  - Outer volume suppression (OVS) [3,4]

Summary

• DWI will likely play a major role in RT workflow
• Online adaptive therapy guided by functional information
  • Potentials enabled by MRgRT systems
• Improved DWI acquisition needed wrt geometric fidelity, resolution and accuracy

Thank you!