Diffusion weighted imaging (DWI) on a MRgRT system

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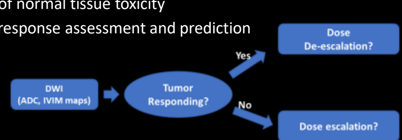
Outline

- 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

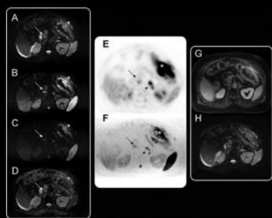
- Improved tumor detection and diagnosis
- Tumor grading and prognosis
- Early prediction of normal tissue toxicity
- Early treatment response assessment and prediction



1. Tsien C, Cao Y, Chenevert T. , *Semin Radiat Oncol.* 2014
2. Metcalfe P, Liney GP, Holloway L, et al. *Technol Cancer Res Treat.* 2013

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

[1] Matthias et al. Investigative Radiology. 2007.

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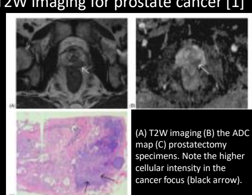
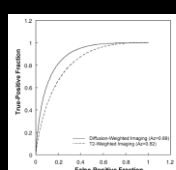
Target detection

- 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).



[1] Miao et al. Eur J Radol. 2007.

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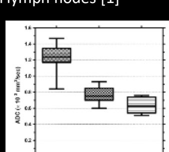
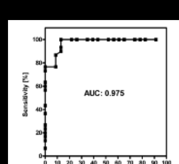
Tumor detection

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





[1] Holzapfel et al. Eur J Radiol. 2009.

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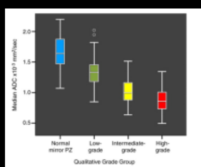
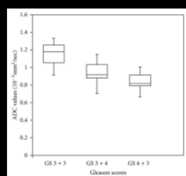
Tumor grading and prognosis

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





[1] Hambrock et al. Radiology. 2011.
[2] Nagarajan et al. Adv Urol. 2012

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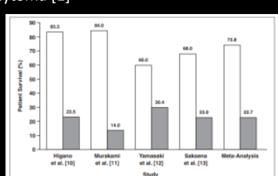
Tumor grading and prognosis

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



[1] Zulfiqar et al. AJR Am J Roentgenol. 2013

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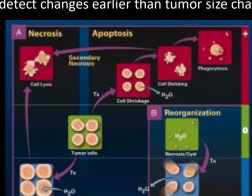
Treatment response prediction

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



[1] Chenevert et al. J Natl Cancer Inst. 2000.
[2] Moffat et al. Proc Natl Acad Sci U S A. 2005

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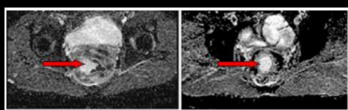
Treatment response prediction

- 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 = $0.87 \times 10^{-3} mm^2/s$ B. After therapy, mean tumor ADC = $1.44 \times 10^{-3} mm^2/s$.

[1] Chenevert et al. J Natl Cancer Inst. 2000.
[2] Moffat et al. Proc Natl Acad Sci U S A. 2005
[3] Hamstra et al. J Clin Oncol. 2008.
[4] Galbán et al. Transl Oncol. 2009.
[5] Kim et al. European Radiology. 2011

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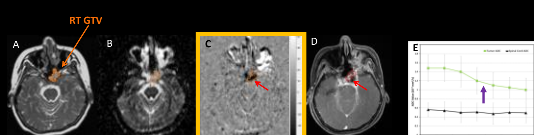
Treatment response prediction

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



MRI pre-RT | Early ADC map during RT | ADC change slope map throughout RT | MRI 21 months post-RT – confirm recurrence

[1] Yang et al. Med Phys. 2016.

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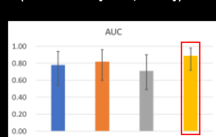
Treatment response prediction

- 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])

CT simulation with GTV contour | DWI @ 5th fraction with b = 500 | ADC map @ 5th fraction



Yu et al. (Wednesday, 8/1/2018) 7:30 AM - 9:30 AM
Room: Karl Dean Ballroom C

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

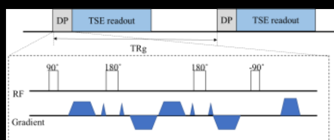
Challenges of implementing on-board DWI

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

[1] Gao et al. Med Phys, 2017

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.



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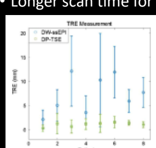
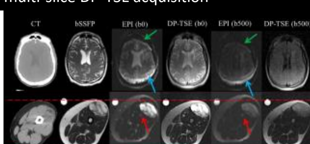
DP-TSE sequence at UCLA

- 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





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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

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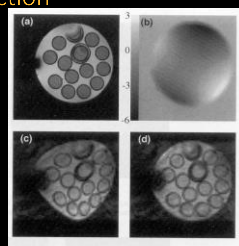
Field map distortion correction

- 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. [1]

$$x_1 = x \pm \frac{\Delta B(x,y)}{G_x},\ y_1 = y + \frac{\Delta B(x,y)T}{G_y \tau},$$



[1] Jezzard et al. Magn Reson Med. 1995

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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.

[1] Chen et al. NeuroImage. 2006. [2] Xiang et al. Magn Reson Med. 2007

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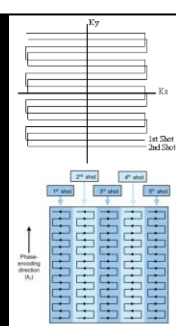
Multi-shot technique

- 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



[1] Butts et al. Magn Reson Med. 1994
[2] Porter et al. Magn Reson Med. 2004.
[3] Holdsworth et al. Eur J Radiol. 2008

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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)

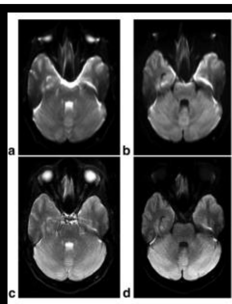

Image from Porter et al. Magn Reson Med. 2004.

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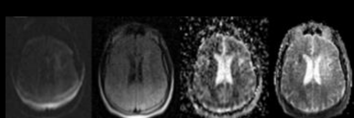
Use other readout module

- 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].



DW-ssEPI (b500) DP-TSE (b500) DW-ssEPI (ADC) DP-TSE (ADC)

[1] Alsop. Magn Reson Med. 1997.
[2] Pipe et al. Magn Reson Med. 2002.
[3] Frank et al. NeuroImage. 2010.
[4] Buxton et al. Magn Reson Med. 1993.
[5] Nguyen et al. Magn Reson Med. 2014.
[6] Sinha et al. JMRI. 1996
[7] Gao et al. Med Phys, 2017

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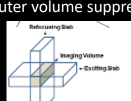
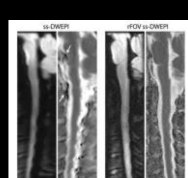
Reduced FOV

- 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]





[1] Feinberg et al. Radiology, 1985. [2] Saritas et al. Magn Reson Med. 2008
[3] Ogg et al. J Magn Reson B, 1994 [4] Wilm et al. Magn Reson Med. 2007

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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