MRI for RT Treatment Planning

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No relevant financial relationships

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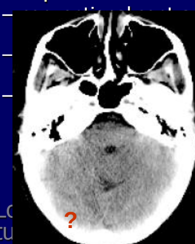
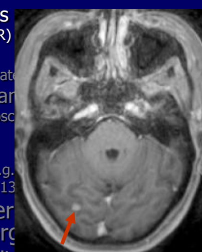
MRI Advantages

- Soft tissue differentiation
- Multiple contrasts
  - – ... ts ... (R)
  - – ... wat ... e image
  - – ... ar ... osc ... e.g. ... 13
- Lc ... er ... ion of tu ... org
  - – beyond electron density (X-ray and CT)


CT


Post-Gd T1WI

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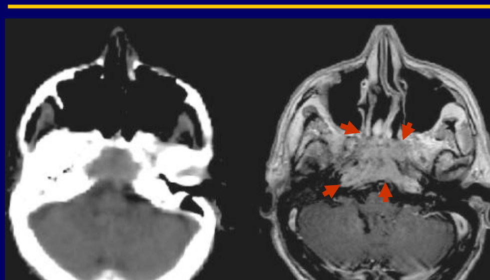
Nasopharygeal Cancer



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Body Sites and Tumors

- Brain tumors
  - – Primary and metastatic tumors
- Prostate cancers
  - – Delineation of whole prostate gland
  - – Localization and Delineation of dominant intra-prostatic lesion
- Cervical cancers
  - – Brachy therapy
- Liver tumors
- HN tumors
  - – Nasopharygeal cancer

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MRI Advantages

- Soft tissue differentiation
- Multiple contrasts
  - conventional contrasts
    - T1 contrast, T2 (or FLAIR) contrast, Post-Gd T1 contrast
  - Advanced contrasts
    - Susceptibility w (T2*), water and fat separation, cortical bone
  - Molecular, metabolic and functional imaging
    - 1H, 31P and 13C spectroscopy imaging
    - DCE and DSC imaging
    - DW and DT imaging
    - Other contrast agents, e.g., SPIO, Eovist,
    - Hyperpolatized 3He and 13C
- Localization, delineation, and characterization of tumors and normal organs
- Integration of target definition and Tx assessment

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Technology Advancements

- High field magnet
- Parallel imaging
- Large Bore size (70 cm)
- Multi-RF transmition
- RF-shimming
- RF coil array/TimCT
- Robust motion suppression pulse sequence

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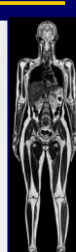
RT Treatment Planning

- Signals, fast acquisition, high resolution, 3D
- RT compatible, embolization equipment
- More uniform RF distribution, e.g., in the liver
- Uniform signal intensity
- Extended coverage and continuous scan like CT
- Better images for motion organ, e.g., liver, HN during swollen



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3D Volumetric T2W image

1x1x1 mm^3 resolution on 3T

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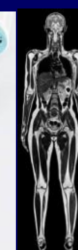

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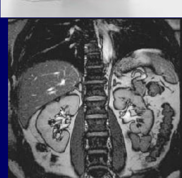

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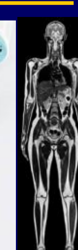

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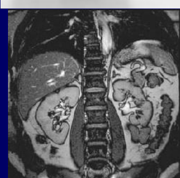
Technology Advancements

- High field magnet
- Parallel imaging
- Large Bore size (70 cm)
- Multi-RF transmition
- RF-shimming
- Modular RF coil arrays/TimCT
- Motion suppression pulse sequence



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RT Treatment Planning

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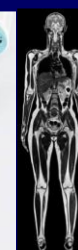

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Technology Advancements

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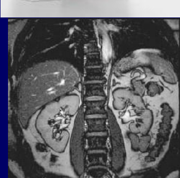

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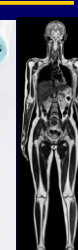
RT Treatment Planning

- Signals, fast acquisition, high resolution, 3D
- RT compatible, embolization equipment
- More uniform RF distribution, e.g., in the liver
- Uniform signal intensity
- Extended coverage and continuous scan like CT
- Reduced organ movement imaging artifacts



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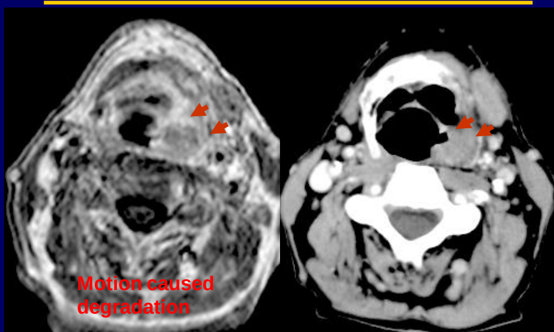
Motion Sensitive?



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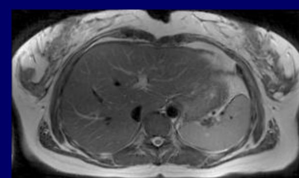
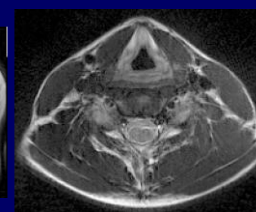
Motion Suppression



T2 w Blade Sequence
Without breath-holding



T2 w Blade Sequence
Without swollen artifacts

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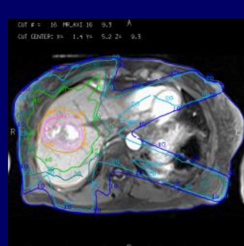
Can we plan solely on MRI?

- Issues:
  - Bore size
  - Distortion
  - Electron density
  - IGRT support



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What sources of geometric errors and solutions are?

Sources of errors

- System level
  - B0 field inhomogeneity
  - Gradient non-linealarity

Physics solutions

- System level
  - Better magnet design
  - On-line gradient distortion correction (GDC)
  - Algorithms to further correct any errors in system level

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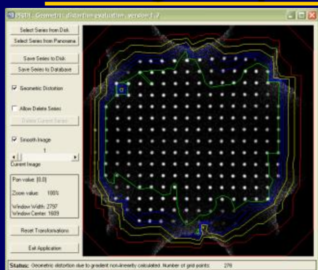
Geometric Phantom to Map Homogeneity



Nina Hoven, Ulleval Hospital, Oslo, Norway

1.0T Philips panoroma scaner

Distiortion-free area:
Sagittal plane: 40 cm AP, 28 cm FH
Coronal plane: 34 cm FH, 36 cm LR
Transverse plane: 32 cm AP, 37 cm LR

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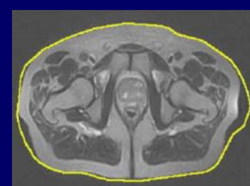
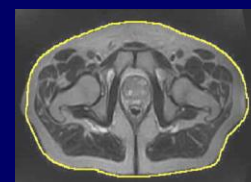
Gradient Distortion Correction





L Chen, Fox Chase Cancer Center,
AAPM Summer School 2006
0.3 T scanner

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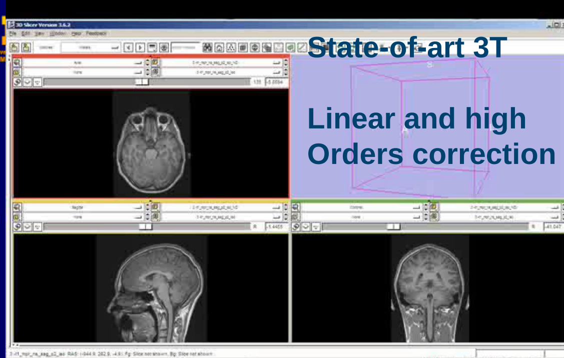

State-of-art 3T

Linear and high Orders correction

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Geometric distortion

Sources of errors

- Patient-level
  - Susceptibility
  - Fat/water chemical shift effect
  - Field strength
  - k-space trajectory
  - Gradient band width
  - Region: air, tissue, & bone interface

Solutions

- Patient-level
  - Solutions:
    - B0 mapping
    - Rectification
    - published 15-20 years ago
  - Sub-mm for small FOV and 1-2 mm for large FOV distortions for SE and GE

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Geometric Accuracy in Brain

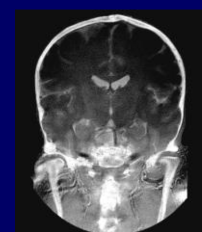
Gradient Echo T1W Images from a 3T scanner

Registered to CT by rigid body transformation

Both superior and inferior portions of brain MRI are well registered to CT

How can you get electron density from MRI?

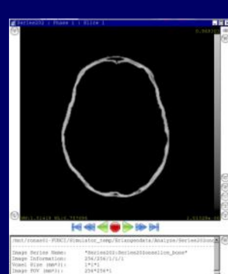
- MR-CT alignment
- Atlas-based density insertion
- MR segmentation:
  - UTE imaging – attempts to directly visualize bone
  - Pattern learning to select candidate bone (versus air) features
- Hybrid approaches



G Bydder UCSD

MRI-based patient modeling for RT planning

- Careful consideration of contrasts in MRI and human models permits image analysis to support:
  - Segmentation
  - Dose calculation
  - Image guided positioning



Molecular/Functional/Metabolic MRI

- Molecular, metabolic and functional imaging
  - 1H, 31P and 13C spectroscopy imaging
  - DCE and DSC imaging
  - DW and DT imaging
  - Other contrast agents, e.g., SPIO, Eovist
- Location, delineation, characterization, assessment of tumors and normal organs

How to validate these imaging techniques for target definition?

- Pathological validation
  - Pathological specimen may not be easily obtained for certain organs, e.g., brain
- Pattern failure
  - Comparing the pattern pre RT with the recurrent pattern
- Prognostic and predictive factors
  - Via assessment of response or outcome to determine the subvolume of the tumor

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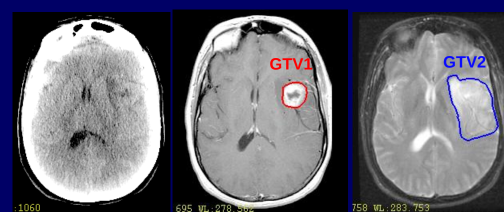
Primary Brain Tumor: GBM



CT	Post-Gd T1W	FLAIR
	Underestimation	Overestimation/ Underestimation

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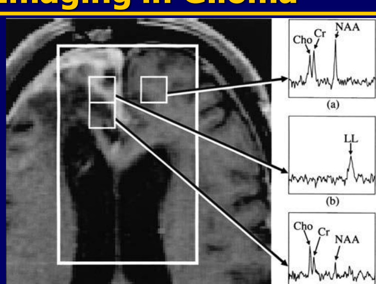
Proton Spectroscopy Imaging in Glioma



Metabolic Abnormality: CNI: Cho/NAA $\geq$ 2.0 SD

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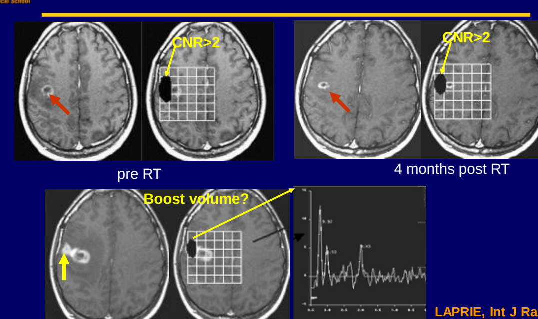
Chan, J Neurosurg, 101:467,2004

Cho/NAA Abnormality in GBM



6 months post RT

LAPRIE, Int J Rad Onc Biol Phys, 70:773-781, 2008

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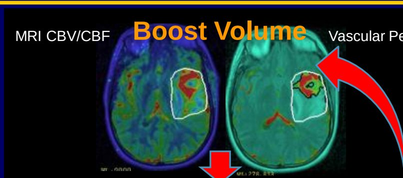
DCE and DSC MRI in GBM



subvolume of the tumor with abnormal CBV/CBF/vascular permeability

outcomes

Cao et al, Cancer Research 2006; Int J Rad Onc Biol Phys 2006

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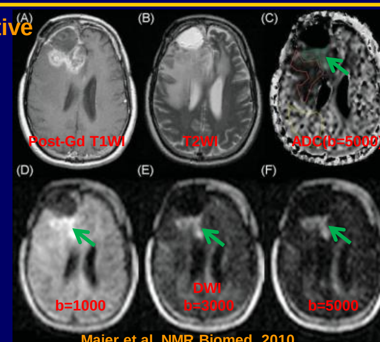
High b-value DWI in GBM

Post-operative



Maier et al, NMR Biomed, 2010

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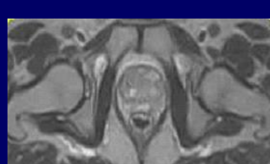
Localization of Prostate Gland

CT



T2W MRI

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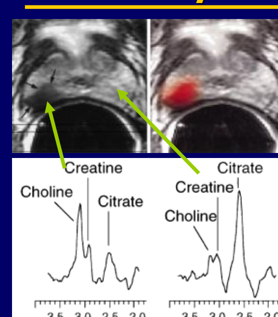
Localization of Intra-Prostatic Cancers by 3D MRSI



Abnormal metabolism: Cho+Cr/citrate ≥ 3SD

Scheidler, Radiology, 213:473,1999

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Pathological Validation of 3D SI for Prostatic Tumor Localization

- UCSF study in 1999
  - 53 patients with biopsy-proved prostate cancer and subsequent radical prostatectomy with step-section histopathologic examination
  - T2W MRI:
    - sensitivity (77% and 81%), specificity (61% & 46%)
  - 3D MRSI (cho+Cr/citrate$\geq$3SD):
    - sensitivity (63%) specificity (75%)
  - MRI+3D MRSI:
    - sensitivity (95% either test), specificity (91%)

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Validation of DCE and MRSI

- Schmuecking et al, Int J Radiat Bio 2009
  - Evaluate quantitative DCE MRI and 1H MRS for the detection of prostate cancers and the delineation of intra-prostate sub-volumes for IMRT
- Groenendaal et al, Int J Rad Onc Biol Phys, 2010

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Delineation of Prostatic Cancers By DCE and MRS

- Schmuecking's study in 2009
  - Comparing quantiative DCE MRI and 1H MRS with these intraprostatic subvolumes with histology and cytokeratin-positive areas in prostatectomy species
  - DCE MRI: (1) 82% of sensitivity and 89% of specificity for localization of prostate cancers in left, right or both lobes; (2)able to detect the lesions > 3mm and/or containing >30% tumor cells; (3) similar to choline PET/CT
  - 1HMRS: (1) 55%-68% for sensitivity and 62%-67% for specificity; (2) able to detect the lesions > 8mm and/or containing >50% tumor cells

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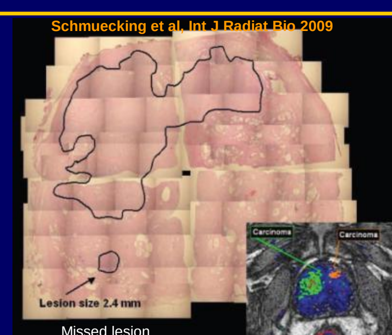
DCE MRI Detection



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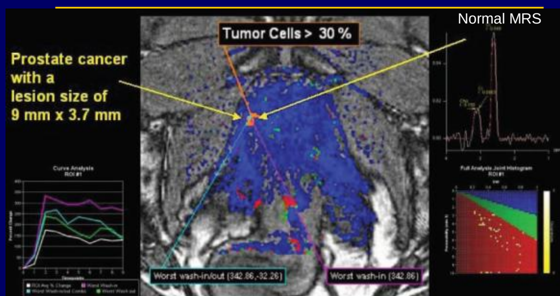
DCE MRI vs MRS Detection



Schmuecking et al, Int J Radiat Bio 2009

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Challenges of MRI for RT

- Electron density
  - UTE MR imaging for bonny structures
- Geometric accuracy
  - System level
  - patient-specific
  - Basic pulse sequences, e.g., GE and SE
  - QA/QC procedures
- Choose spatial resolution and plane orientation
- Position patients in the configuration of RT

Cao RSNA 2009

Challenges of MRI for RT

- Sensitivity and specificity of each contrast or multiple contrasts for tumor delineation
- Reproducibility and uncertainty of metabolic and functional imaging
  - Spatial and amplitude
- Robustness of some of metabolic and functional imaging
- Optimize contrasts
  - Tumor specific
  - Optimal conbinations of contrasts

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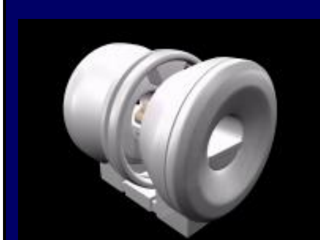
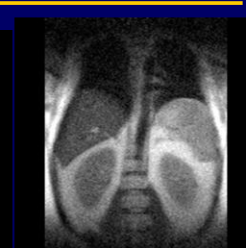
The Renaissance™ System *1000*

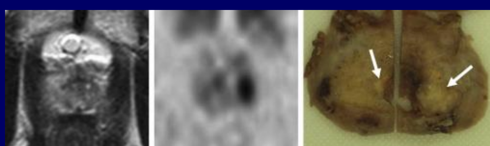




Not Approved for Human or Animal Use

Cao RSNA 2009

Localization of Intra-prostatic cancers by DWI



T2 WI Inversed DWI Pathologic Specimen

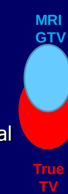
Positive detection rates of 6 observers:
42–73% on T2WI alone
58–80% on T2WI plus DWI

KAJIHARA, Int J Rad Onc Biol Phys, 74:399-403,2009

Cao RSNA 2010

Delineation of Prostate GTVs

- Groenendaal's study
  - Comparing the GTVs delineated on DW and DCE MRI by a rad oncologist with the lesions (22) on prostatectomy specimens by a pathologist
  - 5 dominant intraprostatic lesions (>1cc) and 4 small lesions (>0.56 cc) detected by the Rad Oncologist based upon MRI
  - MRI GTVs of 5 DIL cover 44-76% of pathologoical tumor volumes but have have 62-174% of the pathological tumor volumes



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Delineation of Prostate GTVs

- Groenendaal's study
  - Sources of errors
    - Registration
    - Mis-matched characteristics between DW and DCE MRI (3 DIL), and negative on both DW and DCE MRI (1 DIL)
  - Solution
    - add 5 mm margin to the MRI-GTVs to improve the tumor volume coverage
    - The MRI-GTVs are 2.5-3 times as large as the pathological tumor volumes

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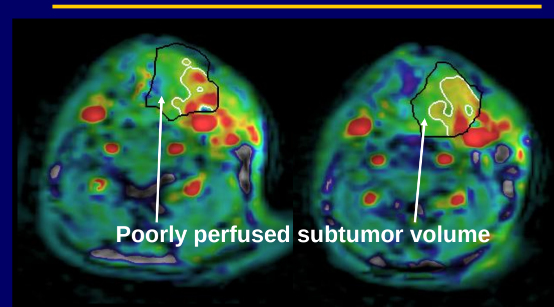
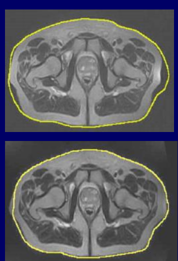
DCE MRI– boost target?



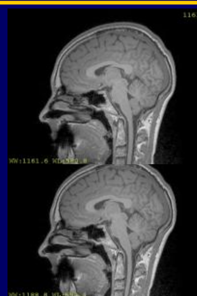
Wang, Eisbruch, Cao, AAPM 2009

Cao RSNA 2010

Gradient Distortion Correction

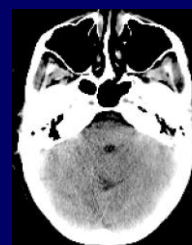


L Chen, Fox Chase Cancer Center, AAPM Summer School 2006
0.3 T scanner

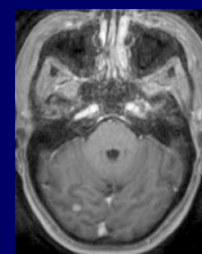


State-of-art 3T scanner

Soft Tissue Differentiation



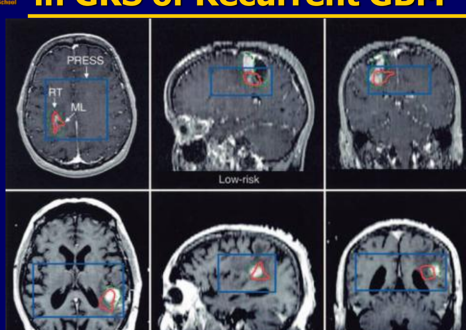
CT



Post-Gd T1WI

Brain metastasis for SRS

CNI Abnormality vs Target in GKS of Recurrent GBM



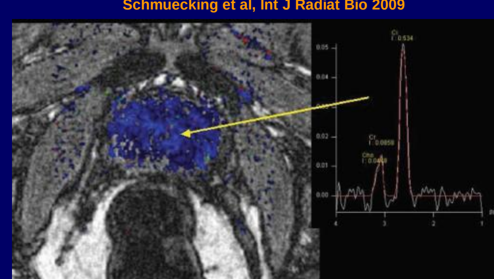
>50% Overlap Survival: 15.7 m

<50% Overlap Survival: 10.4 m

Chan, J Neurosurg, 101:467,2004

DCE MRI and MRS Detection

Schmuecking et al, Int J Radiat Bio 2009



The small lesion was missed by both DCE MRI and 1H MRS