New Developments in Radiation Therapy Targeting

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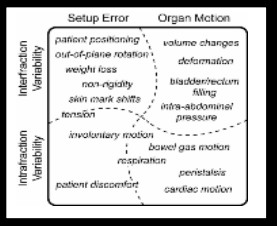
Learning Objectives

- Understand the presence and variety of inter-fraction motion present in radiation therapy.
- Develop awareness of novel approaches being proposed to address these issues.

Targeting Uncertainty in RT

- Setup Variation
  - Patient position/geometry differs planning
  - Commonly inferred by radiography, from skeletal anatomy
  - Not necessarily indicative of target location



- Internal Organ Displacement
  - Tumor and/or normal tissues are positioned differently relative to the skeleton than they were during planning and simulation
- Volume Change and Deformation
  - Geometry of the tumor and/or normal tissues is different from simulation/planning conditions

Respiration-Induced Motion

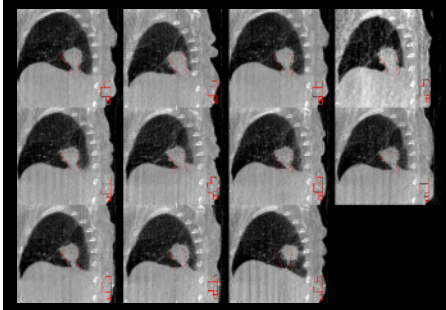
Normal Breathing

Deep Breathing

Breath-hold Exhale

Breath-hold Inhale

Variability in Respiratory Motion



11 CBCT scans with retrospective 4D CBCT sorting and reconstruction

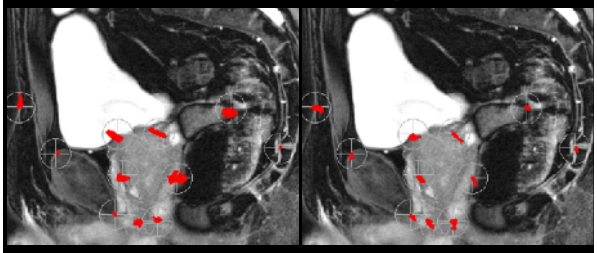
Courtesy of Sonke, van Herk et al, NKI

Prostate Anatomy: Patient Specific Mobility

"Full" Rectum "Empty" Rectum

Prostate Anatomy: Patient Specific Mobility

"Full" Rectum "Empty" Rectum



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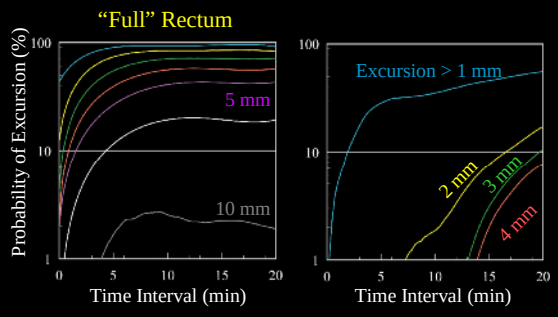
Prostate: Probability of Excursion vs. Elapsed Time



POI = Posterior-Mid Prostate

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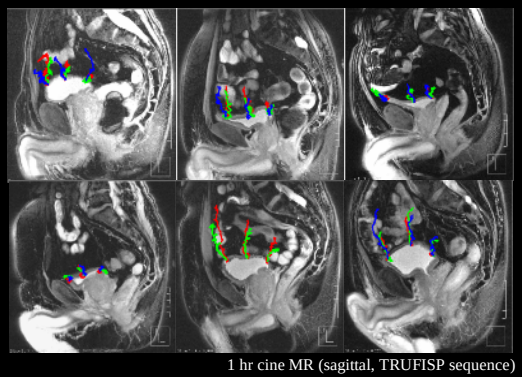
Bladder Filling



1 hr cine MR (sagittal, TRUFISP sequence)

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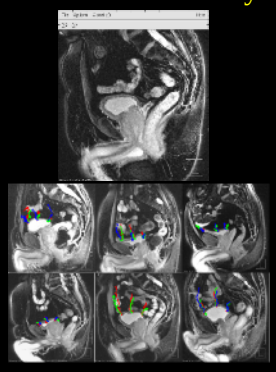
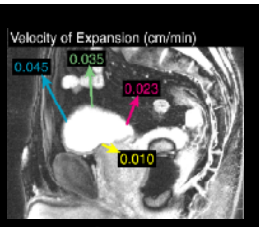
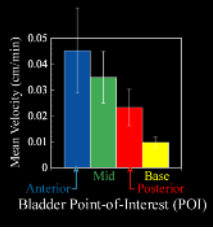
Bladder Wall Velocity

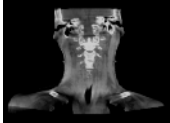






AAPM'07 *TruFISP Sequence, Siemens 1.5T*

Therapy-induced Changes: Head and Neck



7 weeks of therapy with weekly MR imaging

Shrinking Target and Normal Structures

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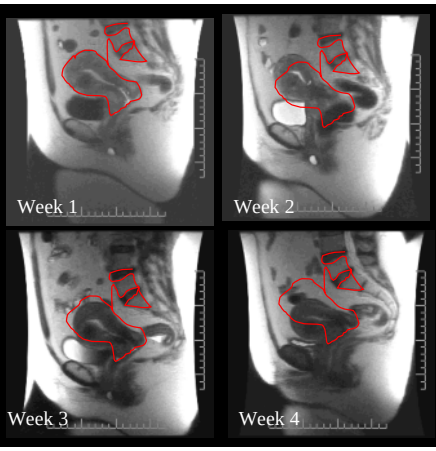
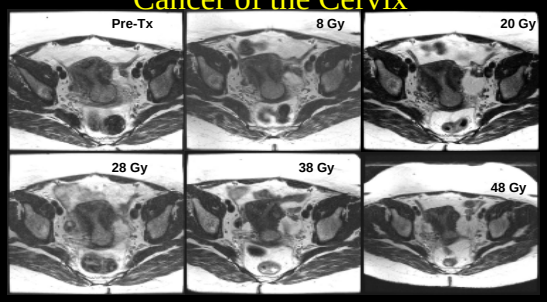
Cancer of the Cervix: Therapy-induced Changes

Sagittal Images



Chan, Dinniwell et al., PMH

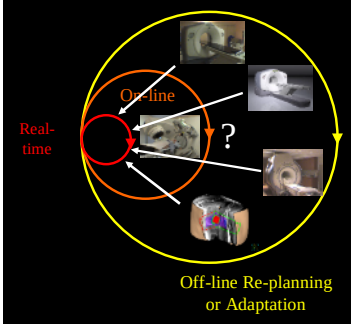
Dose-dependant Volume Changes in Cancer of the Cervix



Serial MRI images of a 54 year old woman with a FIGO IB adenosquamous carcinoma of the cervix.

Chan, Dinniwell et al., PMH

4D IGRT and Temporal Scales of Intervention



- Definitely not exclusive processes
- Efficiency and technology will drive the relative use of these scales.
- Need sufficient information in the on-line imaging to indicate the need for off-line re-planning.
- Off-line planning may require additional and different information.

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Sensitive, Frequent Imaging

- Greater Contrast to Noise
- Higher Sampling Rates
- Less Ambiguous Signals
  - e.g. Volumetric vs. radiographic vs. fiducials
- Lower Acquisition Penalty
  - Time, Dose

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Precise, Responsive Delivery

- Faster Response Times
- Steeper Dose Gradients
- Higher Dose Rates
- Lower Body Doses
- More Degrees of Freedom
- Robustness

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IGRT Technologies


Ultrasound


kV Radiographic


Portal Imaging


Markers


Siemens PRIMATOM™


TomoTherapy Hi-Art™

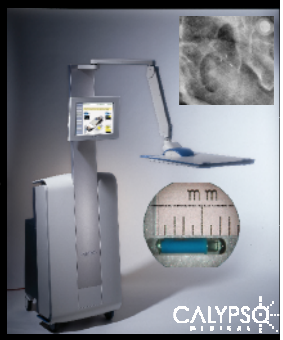

Elekta Synergy™


Varian OBI™

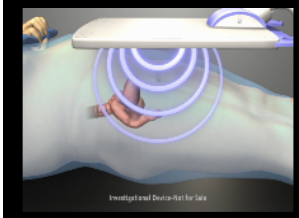
kV CT | MV CT | kV and MV Cone-beam CT

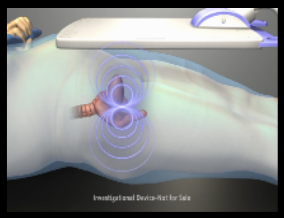
Implantable Sensors

- Wireless AC electromagnetic resonant circuit
  - No external lead wires
  - No internal power supply
- Designed for permanent implantation
- Implant prior to therapy
- Positioned in soft tissue in or near treatment target
- Remains inactive until energized by system console
- 1.85 mm x 8 mm for initial prostate application



Implantable Sensors





Beacon® transponders are excited by a pulse of electromagnetic energy

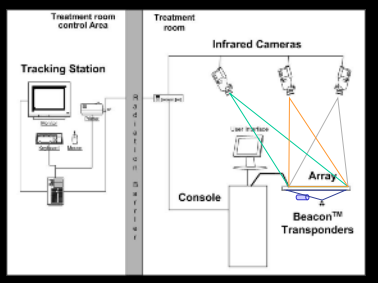
The **transponders** respond with an identifiable signature allowing the clinician to determine tumor location and motion –

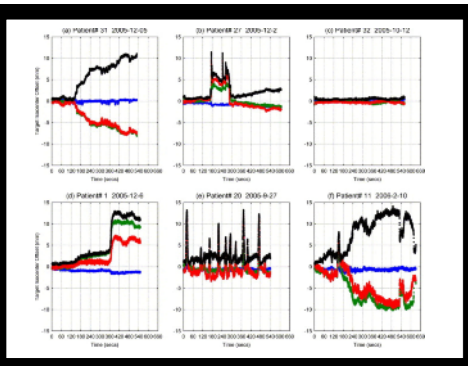
GPS for the Body®

Implantable Sensors:
Localization System

Components

1. **Wireless Transponders**
2. **Array**
3. **Console**
4. **Infrared Cameras**
5. **Tracking Station**





Examples of behaviors observed in the continuous tracking data: (a) continuous target drift; (b) transient excursion; (c) stable target at baseline; (d) persistent excursion; (e) high-frequency excursions; (f) erratic behavior. Red: vertical, green: longitudinal, blue: lateral, black: vector length.

From Kupelian et al. Int. J. Radiation Oncology Biol. Phys., Vol. 67, No. 4, pp. 1088–1098,

Comments on Implantable Sensors

- Raises interesting feedback/intervention questions for the therapist at the unit.
  - Beam interruption
- Are these excursions relevant in conventional fractionation? Hypo-fractionation?
- Is there a sub-group of patients that significantly benefit? E.g. Continuous drift?

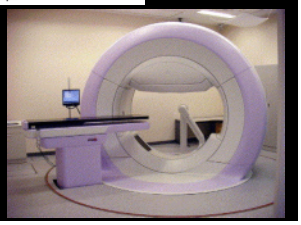
PHYSICS CONTRIBUTION

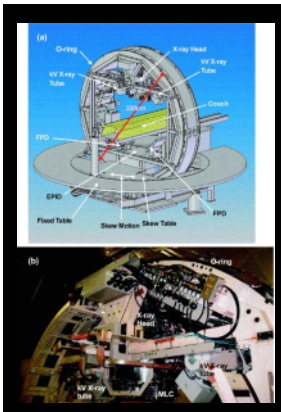
DEVELOPMENT OF A FOUR-DIMENSIONAL IMAGE-GUIDED RADIOTHERAPY SYSTEM WITH A GIMBALED X-RAY HEAD

Yuichiro Kamino, M.S.,* Keiko Takayama, M.D.,*† Masaki Kokubo, M.D., Ph.D.,‡ Yuichiro Narita, Ph.D.,‡ Eiichiro Hiraoka, Ph.D.,* Noriyuki Kawagoe, D.S.,* Takashi Mizowaki, M.D., Ph.D.,‡ Yasushi Nagata, M.D., Ph.D.,‡ Takehiro Nishidai, Ph.D.,§ and Masahiro Hiraoka, M.D., Ph.D.‡

*Mitsubishi Heavy Industries, Ltd., Tokyo, Japan; †Department of Radiation Oncology and Image-applied Therapy, Graduate School of Medicine, Kyoto University, Kyoto, Japan; ‡Institute of Biomedical Research and Innovation, Kobe, Japan; §Kyoto College of Medical Technology, Kyoto, Japan

Exterior view of the system. The O-ring is skewed in the counterclockwise direction.





(a) The basic structure is the O-ring with diameter of about 330 cm. (b) The structure around the X-ray head is shown. The X-ray head is hidden behind the support structure and only the multileaf collimator (MLC) can be seen. The kV X-ray tubes are installed on the both sides of the MLC.

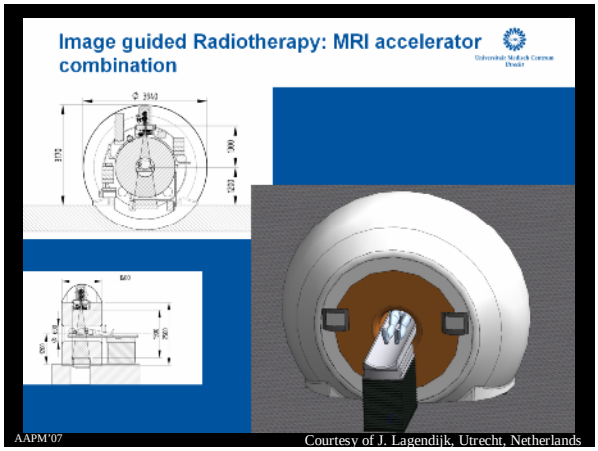
(a) Cone beam computed tomography image of the pelvis for a prostate case. The X-ray parameters were 120 kVp, 200 mA, 10 ms, and 800 mAs. The total monitoring dose was 19.4 mGy. (b) The conventional X-ray computed tomography image of the same area of the same patient.

Kamino et al. IJORBP, 2006

Comments on MHI Unit

- Imaging for respiratory motion and adjustable collimation for compensating.
- Volumetric and fluoroscopic functionality.
- Maintained non-coplanar features.
- Large at 3.3 m in diameter

Courtesy of J. Lagendijk, Utrecht, Netherlands



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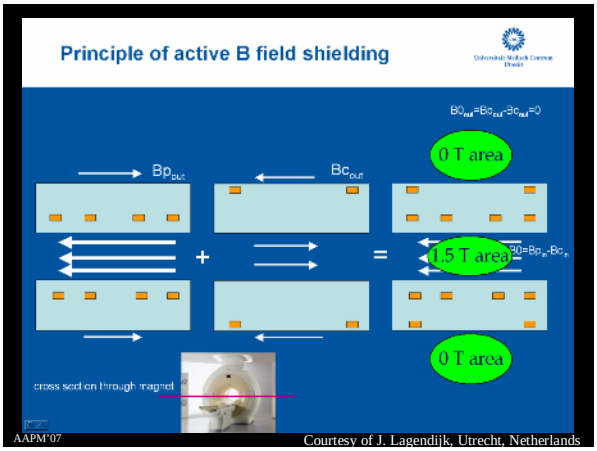

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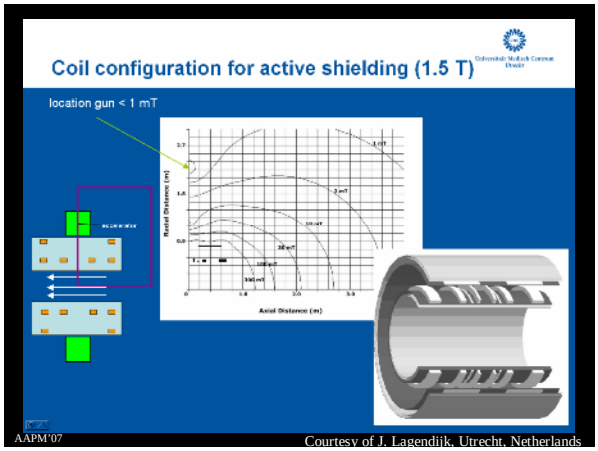

AAPM'07 Courtesy of J. Lagendijk, Utrecht, Netherlands

Comments on Utrecht MR Unit

- Leverages existing MR design.
- Why choose the high (1.5T) field strength?
- How do you achieve repair and maintenance in 1.5 T context.
- General MR questions:
  - Geometric Distortion Corrections (B, chemical shift, susceptibility)
  - Pre-clearance of patients for MR
  - Throughput issues
  - Dosimetry challenges

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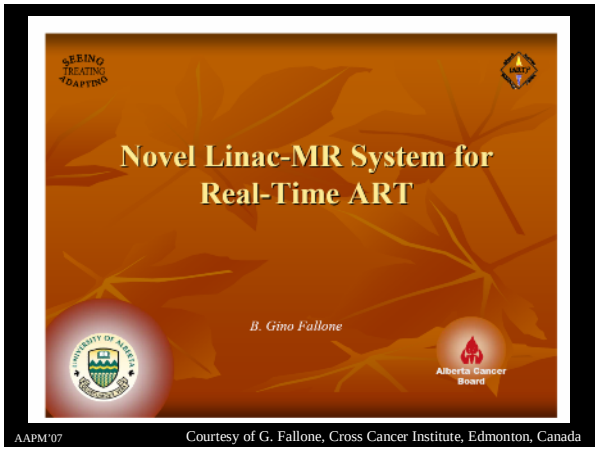
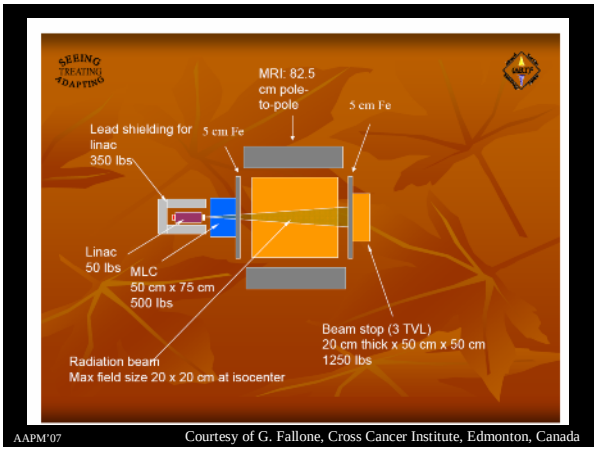


AAPM'07 Courtesy of G. Fallone, Cross Cancer Institute, Edmonton, Canada



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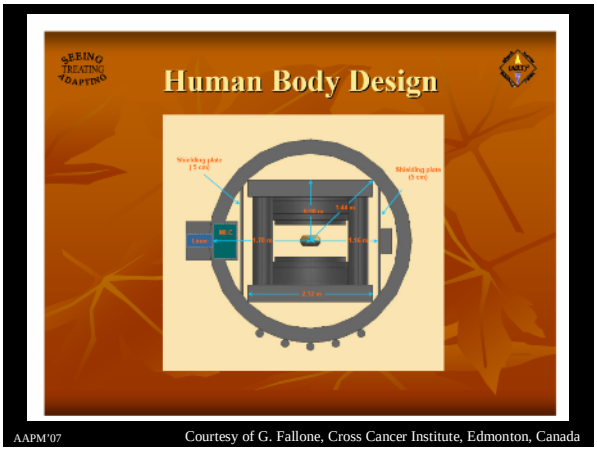

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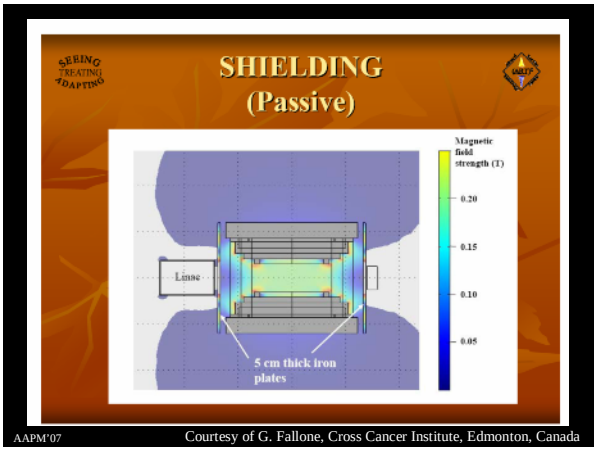

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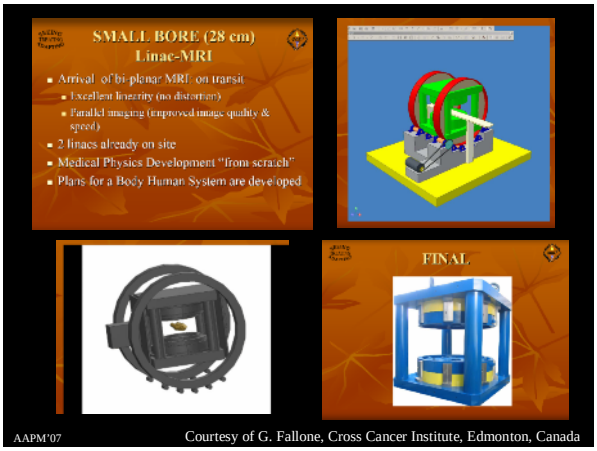

AAPM'07 Courtesy of G. Fallone, Cross Cancer Institute, Edmonton, Canada

Comments on Edmonton MR-guided Accelerator

- Sufficient field strength with 0.2T?
- Significant SAD in Human Scale: ISL->1/3 D_{rate}

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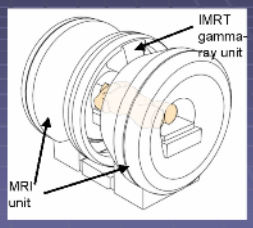
Prototype of the Renaissance™ Device

- Co-registered and gantry mounted
  - Open split solenoid MRI
  - MLC-Based cone beam IMRT unit with axial patient access
  - Multiple sources…
- Imaging during beam-on
- Daily optimization
- Daily recording of delivered dose



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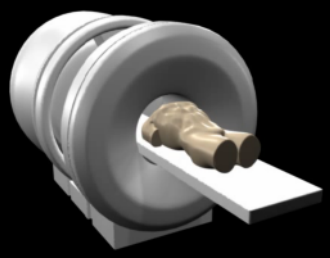
Courtesy of J. Dempsey



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Courtesy of J. Dempsey

Comments on Viewray Proposal

- Feasibility of MR imaging during RT delivery?
  - Cobalt is quite.
- How well does ^{60}Co perform?
  - Dose rate, conformality

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Summary

- Precise and accurate radiation delivery continues to be a challenging task.
- Significant advances in IGRT have been made in the past 5 years.
- Increased activity in development of new image-guided megavoltage photon therapy systems.
- Interplay between real-time, adaptive, and response assessment feedback on these systems promises an exciting future for RT.

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Acknowledgements

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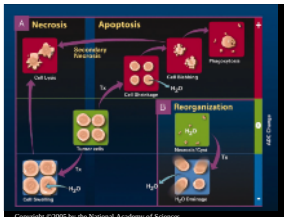
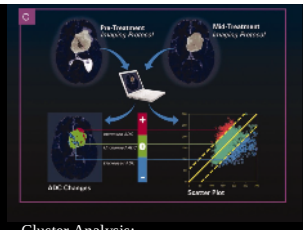
Michael Sharpe – Princess Margaret Hospital, Toronto
P. Chan - Princess Margaret Hospital, Toronto





20 Patients RT, Chemo or both

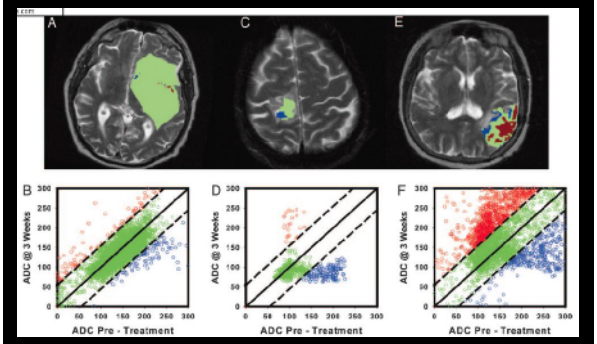
Pre-Tx and Intra-Tx Course MR Diffusion (Apparent Diffusion Coefficient, ADC)

Cluster Analysis:

100% sensitivity and a specificity of 100% for distinguishing PR patients from SD and PD patients

The predictive values and overall accuracy for discriminating PR, SD, and PD patients at 3 weeks post-treatment initiation were found to be 100% for all 20 patients.

Moffat, Bradford A. et al. (2005) Proc. Natl. Acad. Sci. USA 102, 5524-5529



Persistent Disease | Stable Disease | Partial Response

Moffat, Bradford A. et al. (2005) Proc. Natl. Acad. Sci. USA 102, 5524-5529