Challenges of Post-Treatment and Real-Time Imaging of Dose Deposition in Proton Therapy

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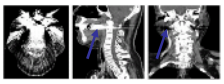
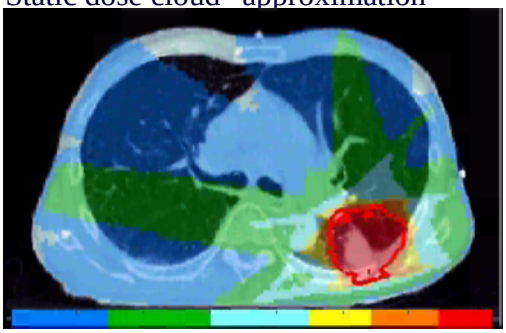
Sources and magnitude of range uncertainties

- Differences between treatment preparation and treatment delivery (~ 1 cm)
  - Daily setup variations
  - Internal organ motion
  - Anatomical/ physiological changes during treatment
- Dose calculation errors (~ 5 mm)
  - Conversion of CT number to stopping power
  - Inhomogeneities, metallic implants
  - CT artifacts



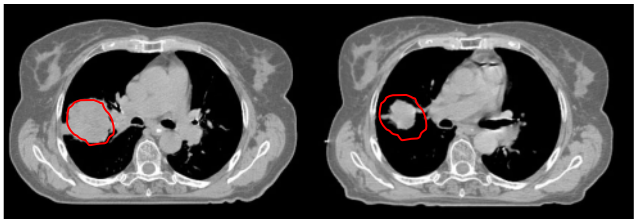
Photon planning: "Static dose cloud" approximation



Proton planning: Tumor shrinkage

Initial Planning CT
GTV 115 cc

5 weeks later
GTV 39 cc



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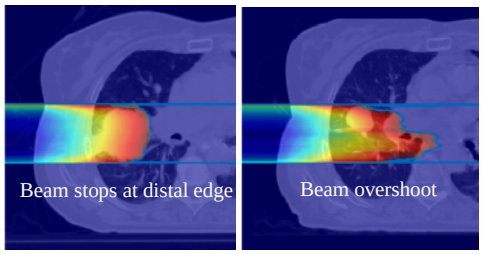
Proton planning:
Tumor shrinkage results in proton overshoot

Planning CT (T40%) CT after 5 weeks (T40%)



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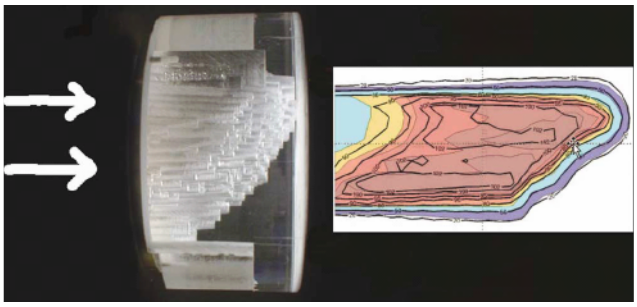
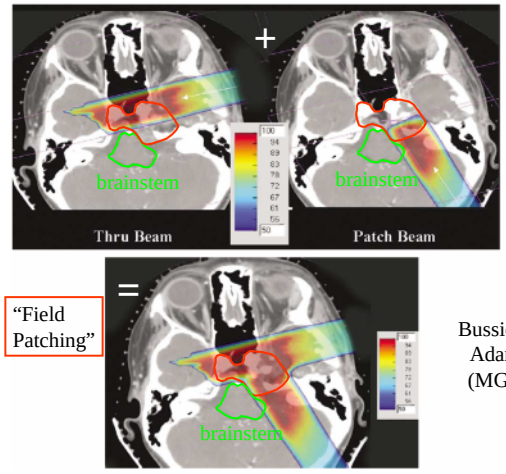
Adding a distal margin





"Field Patching"

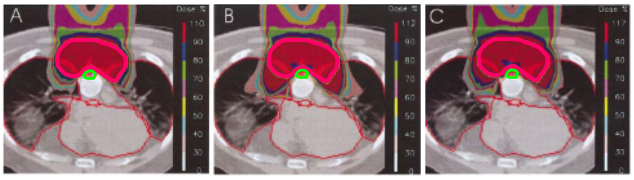
Bussiere, Adams (MGH)

IMPT plan – "proximal patching"

Lomax et al.: Med. Phys. 28:317-324, 2001

Unkelbach et al.: PMB 52:2755-2773, 2007

Sensitivity analysis



Nominal | Range overshoot (10% HU errors) | 5 mm setup error (worst case)

Lomax et al.: Med. Phys. 28:317-324, 2001

Unkelbach et al.: PMB 52:2755-2773, 2007

Solutions to range uncertainties:

Solution 1:

Account for range uncertainties during treatment planning

- Compensator smearing (thinning)
- Field patching
- Robust planning for range uncertainties

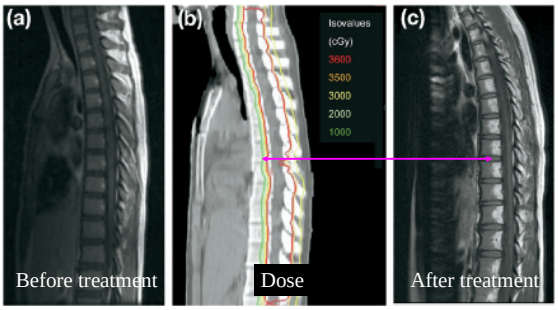
Solution 2:

Reduce range uncertainties through imaging

- In-vivo dose imaging:
  - MR imaging and other techniques
  - PET: offline and in-room
  - Prompt gamma imaging

Reducing range uncertainties: Measurements

MR scan after treatment



Krejcarek, Yock, et al.
IJROBP 2007;68(3):646-649

Nuclear interactions of protons

Int. J. Radiation Oncology Biol. Phys., Vol. 65, No. 1, pp. 1–7, 2006

0360-3016/06/$–see front matter

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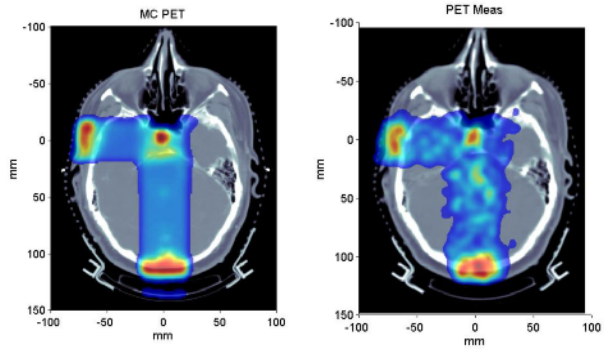
CRITICAL REVIEW

INTENSITY-MODULATED RADIATION THERAPY, PROTONS, AND THE RISK OF SECOND CANCERS

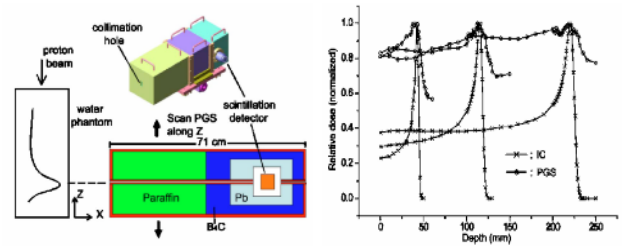
ERIC J. HALL, D.PHIL., D.SC.
Center for Radiological Research, Columbia University Medical Center, College of Physicians and Surgeons, New York, NY

Pituitary Adenoma, PET imaging



Parodi, Knopf, et al., MGH

Measurement of prompt gammas



C-H Min & CH Kim, Applied Physics Letters 89, 183517, 2004

Symposium "Imaging of dose deposition…"

- Theodore Hong
  (Mass. General Hospital, Boston, USA)
  "Clinical Significance of In-Vivo Proton Range Detection and Potential of MRI Scanning After Proton Therapy"
- Katia Parodi
  (Heidelberg Ion Therapy Center, Germany)
  "Latest Developments in PET Verification of Proton Therapy"
- Jong-Won Kim, H. Kubo, T. Tanimori
  (National Cancer Center, Korea)
  "Prompt Gamma Measurements for the Verification of Dose Deposition in Proton Therapy"