SnapShot IMRT with compensators and FFF beams

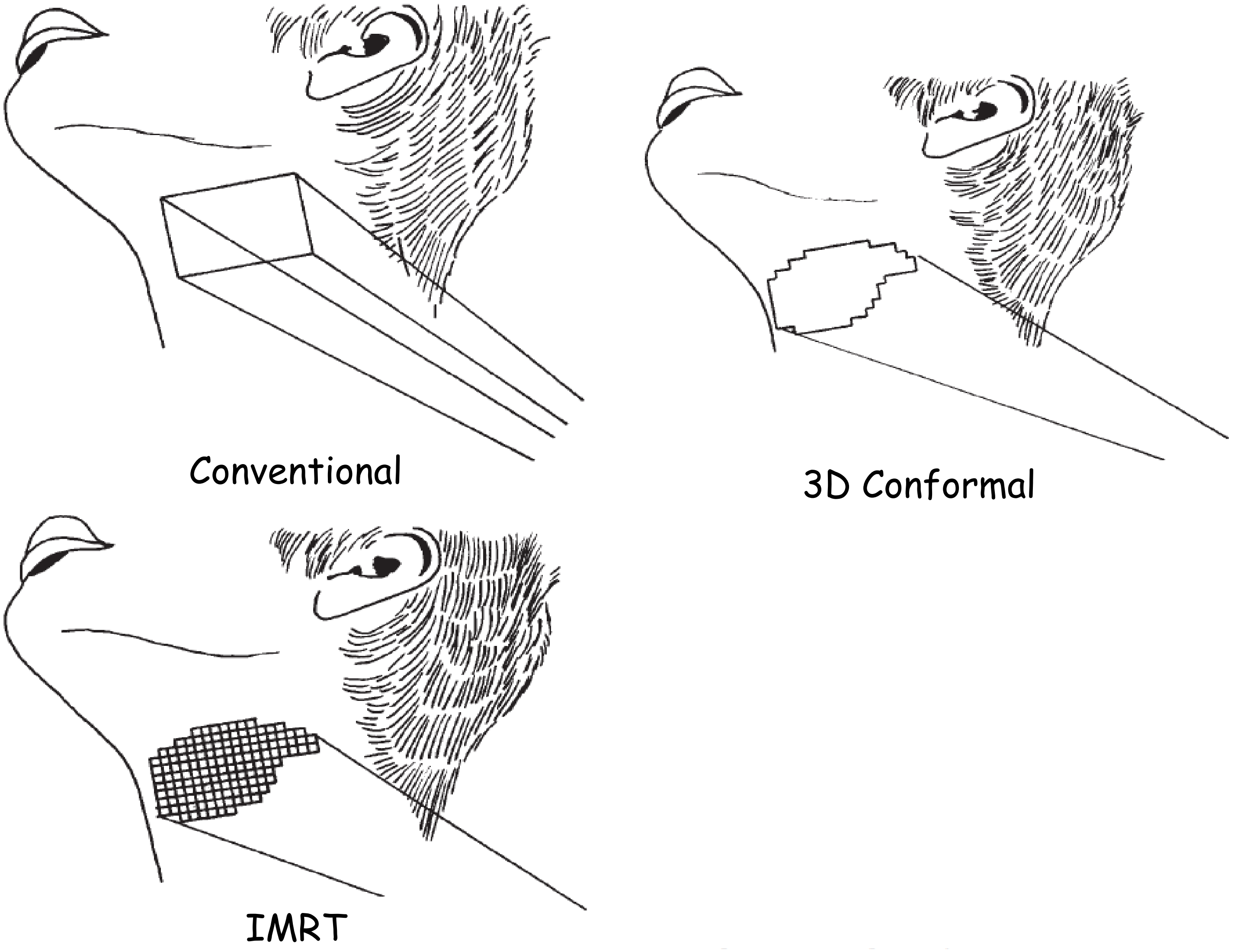
Vladimir Feygelman, PhD

[1] Moffitt Cancer Center, Tampa, FL, USA

Disclosure

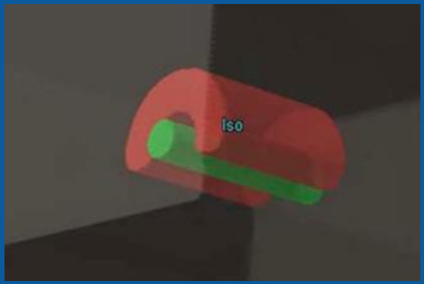
- VF has a sponsored research agreement with .decimal.

A short history of radiotherapy



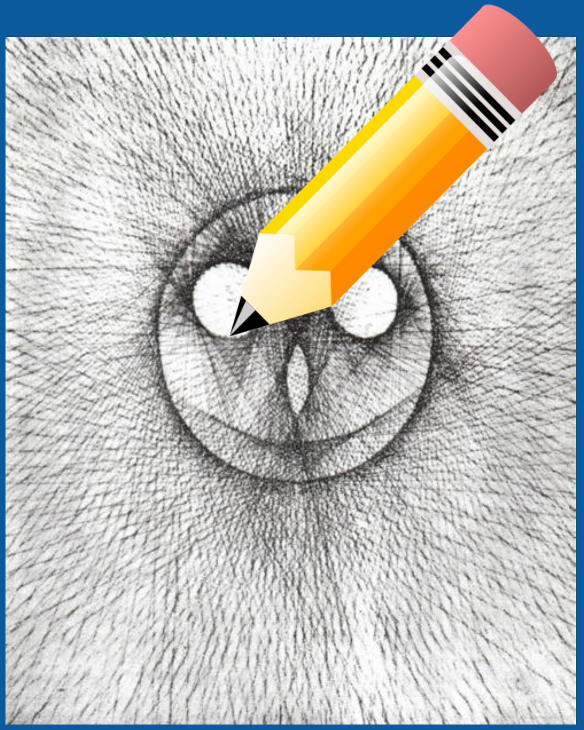
What is IMRT

- Delivery of radiation to the patient with non-uniform fluence, optimized to produce highly conformal dose distributions in patient
- The IMRT's claim to fame is *conformal avoidance*, particularly around *concave* targets



Pre-history of IMRT

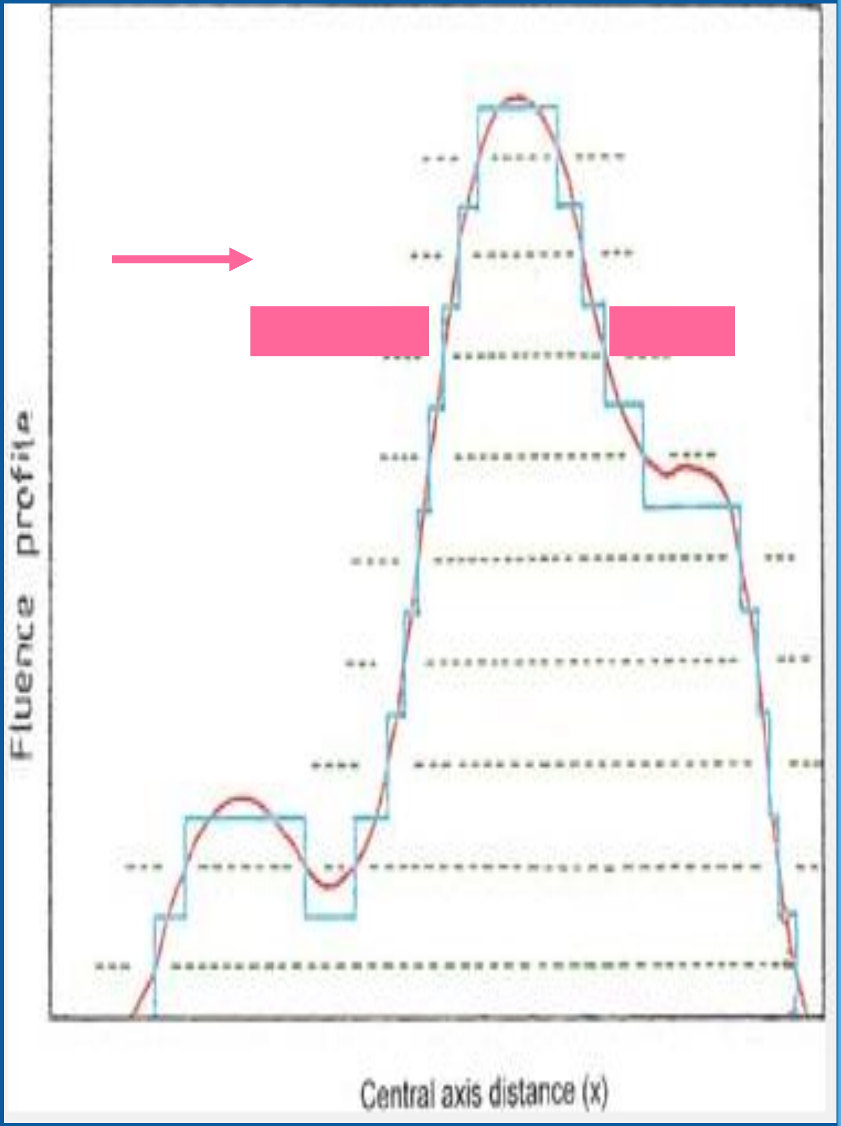
- Hind sight is always 20/20…
- Precursor of the IMRT concept
- Arbitrary picture with a pencil and a ruler by drawing straight lines with different 'intensities'
- Requires both ends of the pencil



George D Birkhoff, 'On drawings composed of uniform straight lines'. (1940)

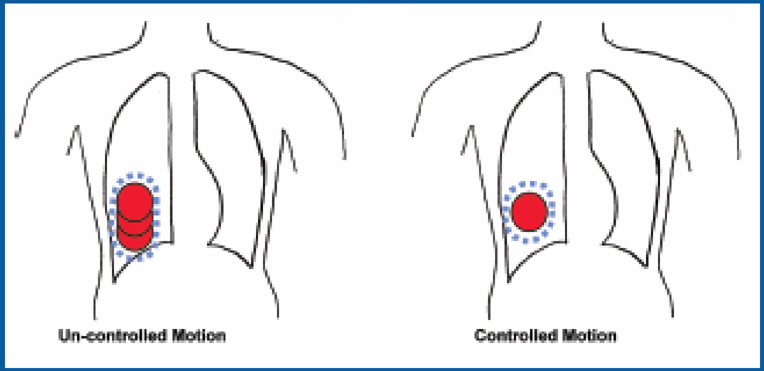
MLC solution

- The aperture is split into small MLC-defined beamlets (segments), each irradiated for only portion of a time
- Trailing leaf shapes the positive slope (Lt)
- Leading leaf shapes the negative slope (Rt)



Enter tumor motion

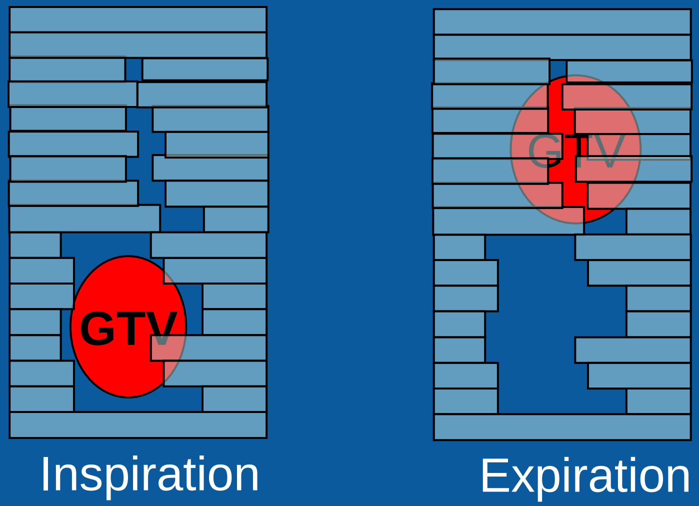
- Simple solution: encompass the motion (ITV approach)
  - Increased irradiated volume
- Or somehow control the motion



IMRT with ITV:

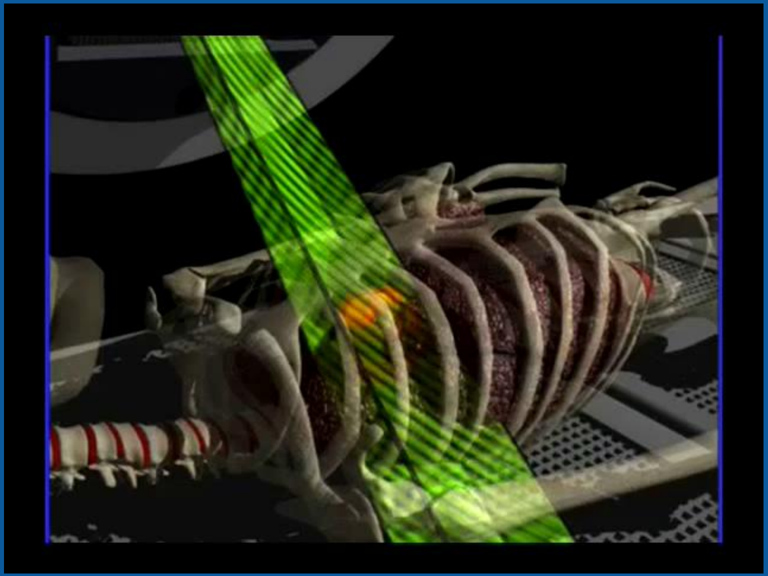
Tumor motion can affect dose distribution

- Interplay effect: simultaneous tumor and MLC motion



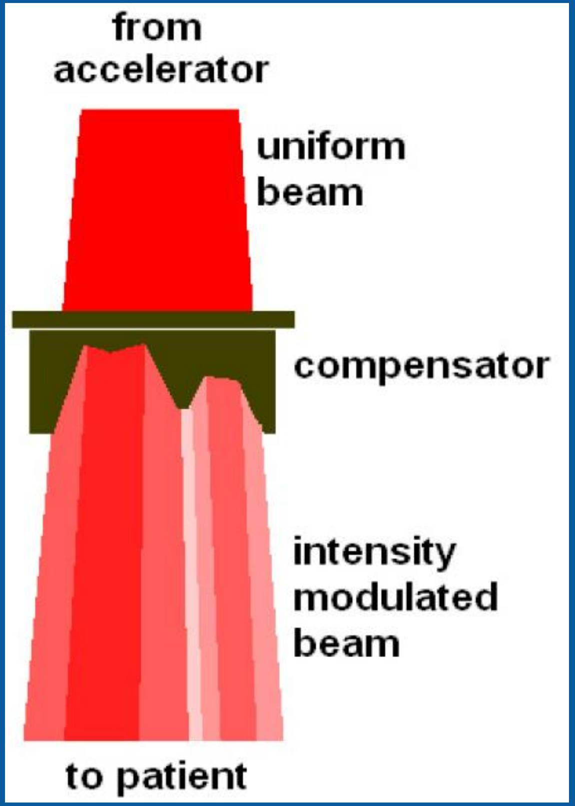
IMRT with Gating

- Interplay eliminated
- Inefficient delivery – duty cycle



Compensators – another way to modulate the beam

- Conceptually simple
- Typically made of brass
- Fast delivery per beam
- The whole aperture is irradiated simultaneously – no interplay effect



Compensators vs. MLC IMRT in presence of motion

- Although smaller for compensators, interplay effect largely washes out for ~30 fractions with any delivery
- For a few fractions, dose deviation is appreciably larger with the MLC – implications for SBRT

Effects of intra-fraction motion on IMRT dose delivery: statistical analysis and simulation

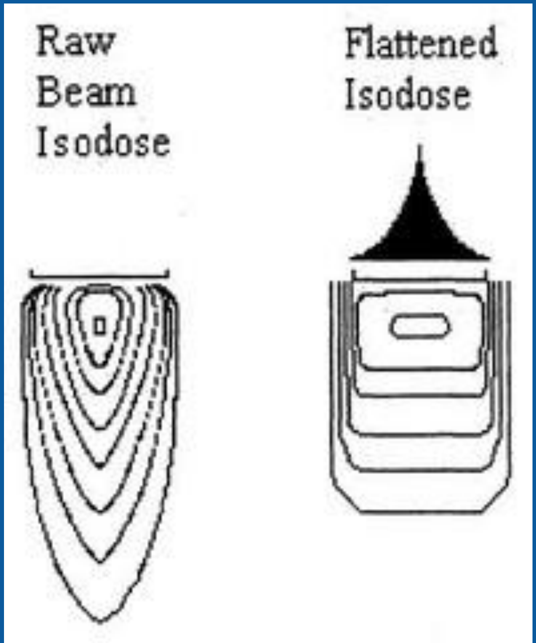
Thomas Bortfeld, Kimmo Jokivarsi, Michael Goitein, Jong Kung and Steve B Jiang

Department of Radiation Oncology, Massachusetts General Hospital and Harvard Medical School, Boston, MA 02114, USA

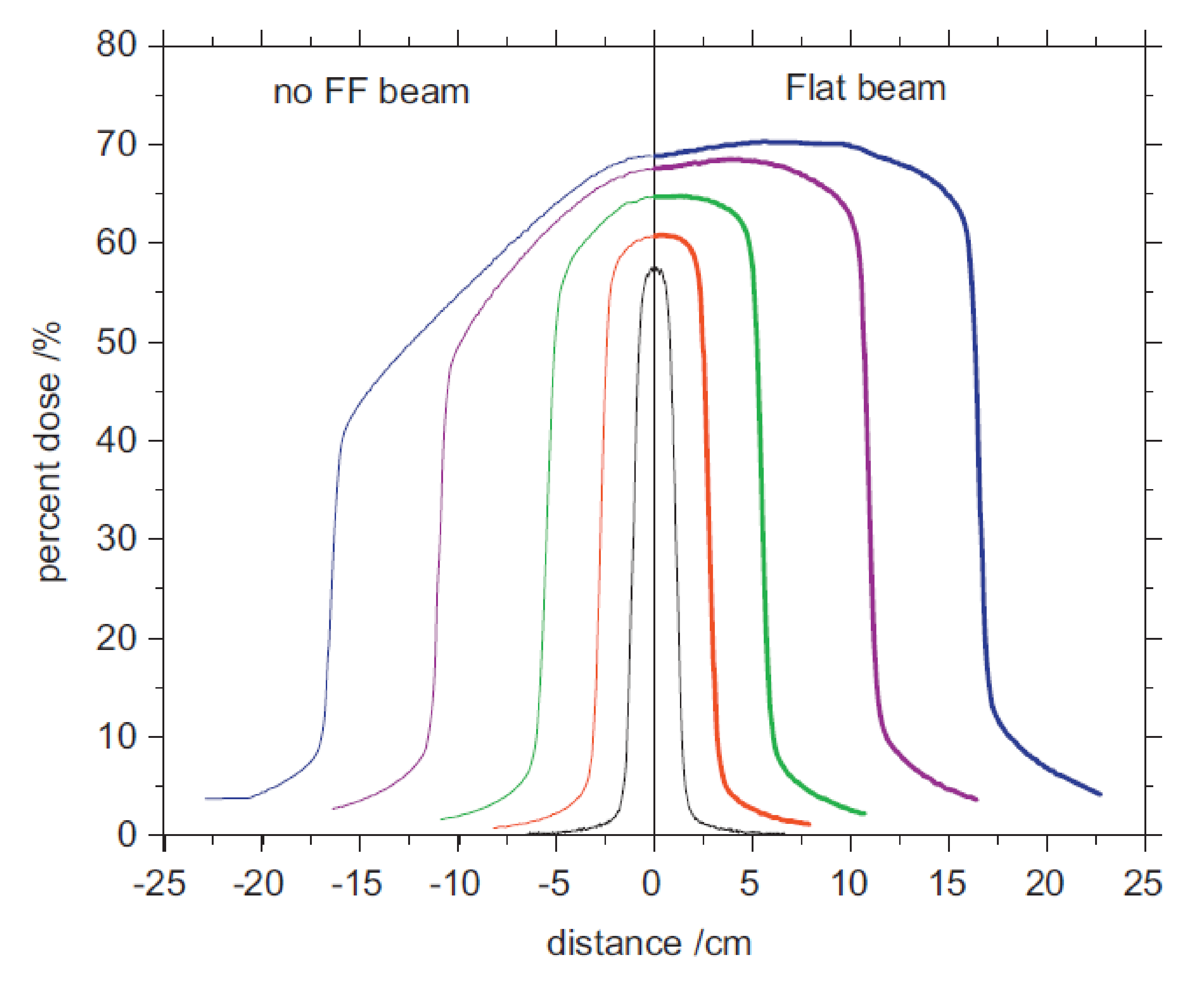
Received 26 February 2002
Published 20 June 2002
Online at stacks.iop.org/PMB/47/2203

Enter FFF beams…

- In order to mitigate the effect of high-energy Bremsstrahlung photons being emitted primarily in the forward direction and thus make a therapeutic beam more homogeneous
- The use of the flattening filter created a flat beam and made it possible to treat patients based only on hand calculations (or minimal treatment planning)
- However it did so by reducing dose rate in the center

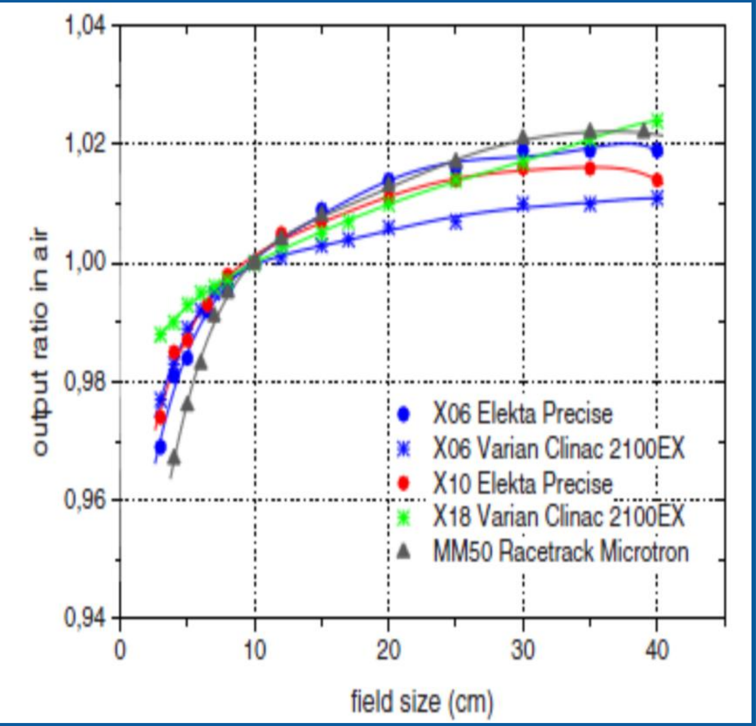


Dose profiles with and without FF – 6X



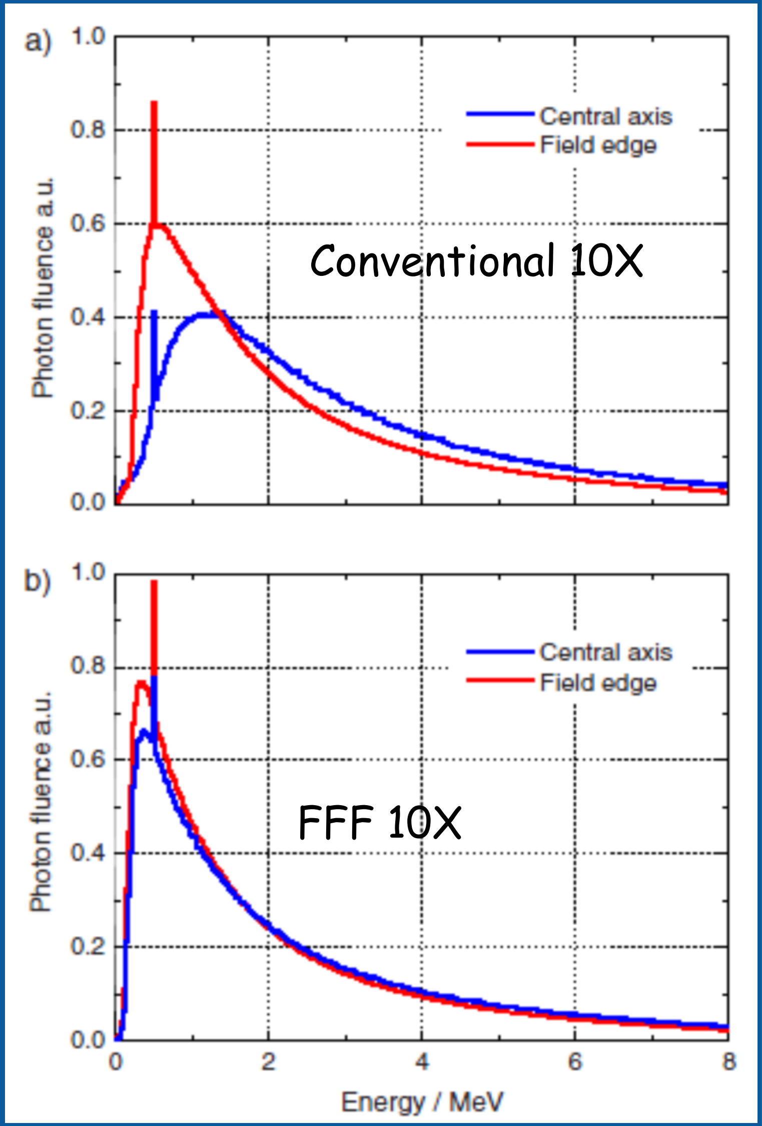
FFF beams

- The main source of head scatter – the FF – is removed
  - Reduced head-scatter variation with field size (S_c max 1.02 vs 1.06+)
  - Collimator exchange effect disappears
- More lower energy photons:
  - 6MV FFF PDD ~ 4-5MV standard beam



FFF beams

- Much less energy spectrum variation across the field



FFF claim to fame:

- High dose rates
  - Varian TrueBeam
    - 1400 MU/min 6X FFF
    - 2400 MU/min 10X FFF
    - Conventional 600 MU/min all energies
- Should shorten treatment time and/or improve gating efficiency

3D and dose rate

- For 3D forward planning beam-on time inversely proportional to nominal dose rate
    - Full dose rate advantage: beam-on time reduced by a factor of 1400/600 = 2.3
- Only possible for smaller targets because of non-flat beam

MLC-IMRT/VMAT and dose rate

- Need/want modulated beams in many cases
  - Only partial dose rate advantage achievable with MLC IMRT/VMAT because beam-on time is largely controlled by MLC/gantry speed

Compensator IMRT and dose rate

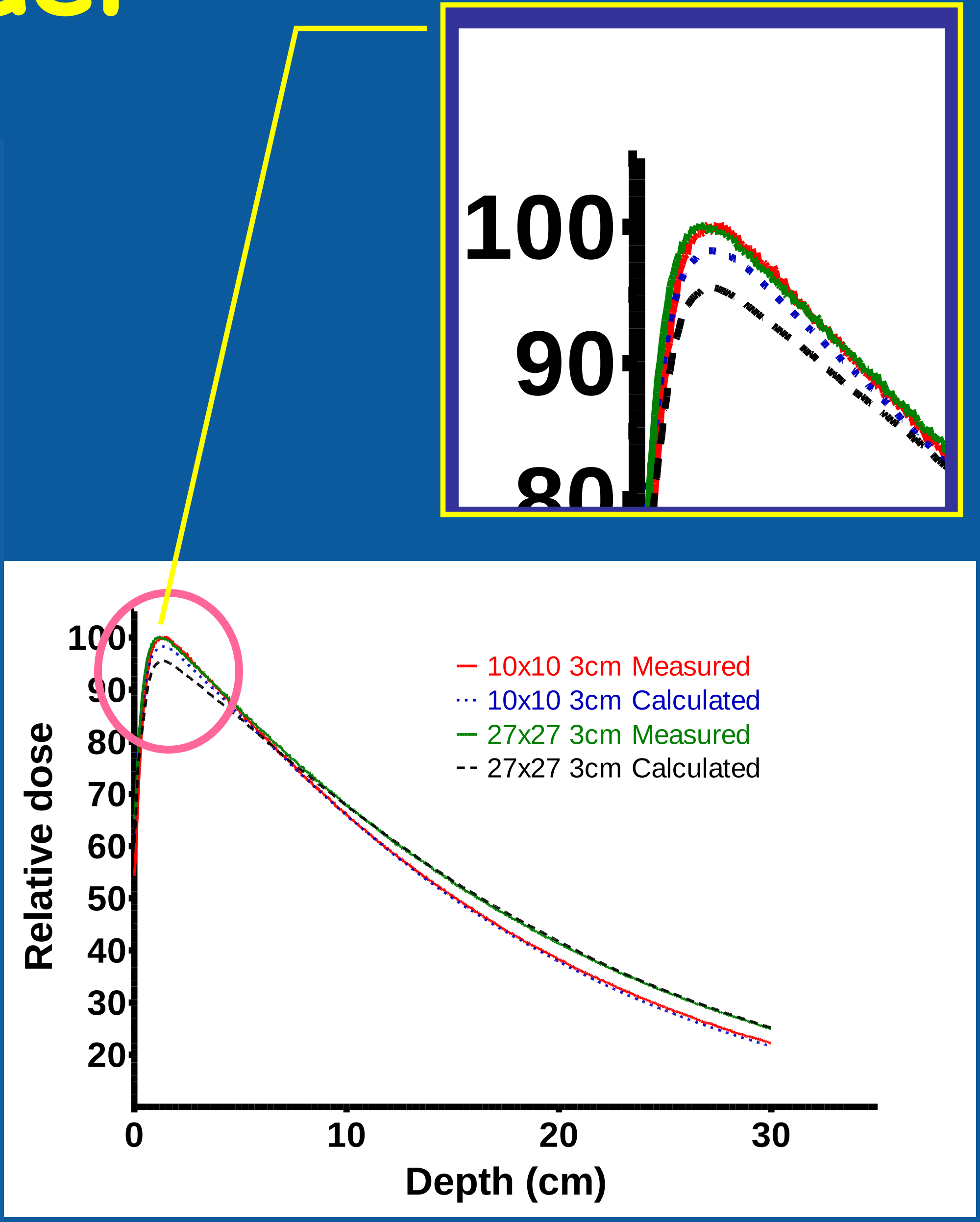
- Same as 3D – full dose rate advantage
- Need to commission FFF with compensators in Pinnacle

Commissioning FFF beam with compensators

- Like wedges, compensators modify the beam
  - Each physical wedge often has its own PDD model in Pinnacle, sometimes further divided by field size
- Unlike wedges, compensators vary in shape
  - Have to have a single model spanning the range of thicknesses and field sizes. Modeling scatter is a challenge

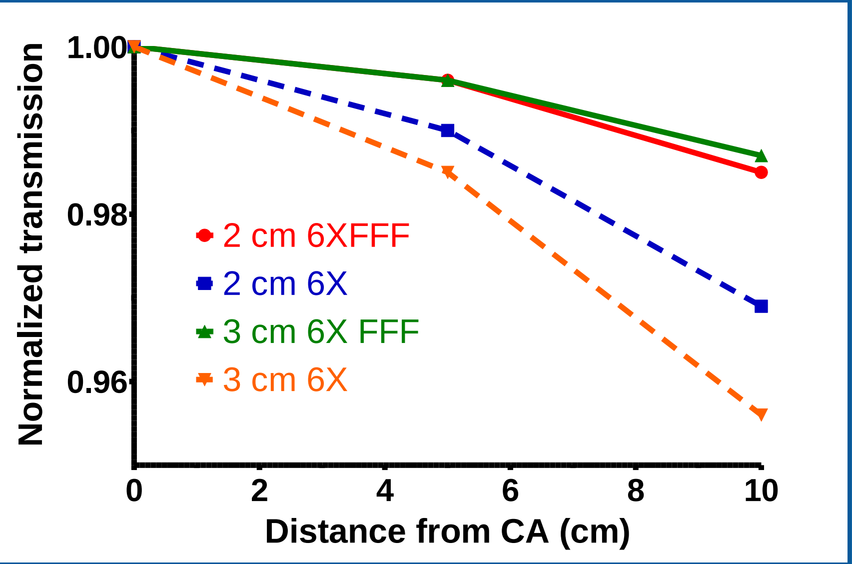
PDD model

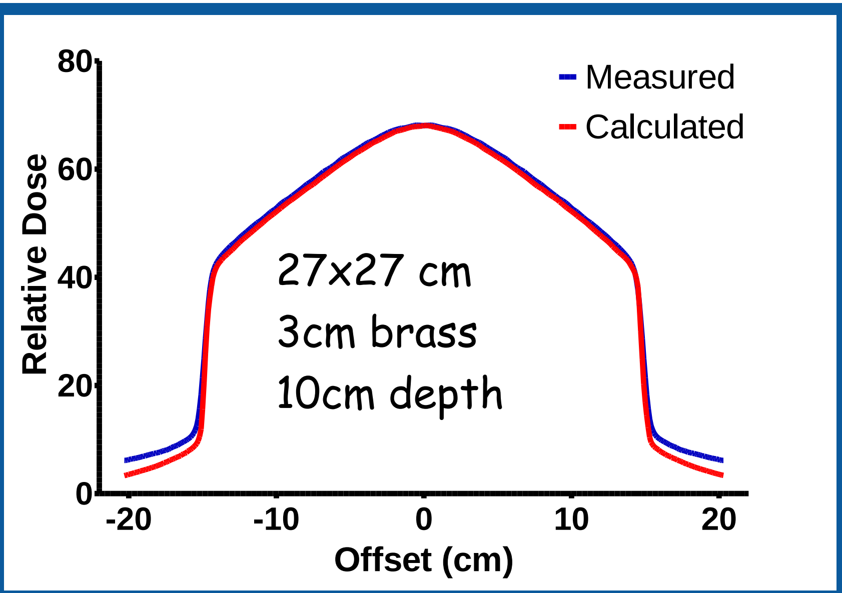
- Open field model is used – beam hardening in compensator is built into algorithm
- Scatter from brass is not handled very well – disagreement at shallow depth
  - Similar to conventional 6X with compensators
  - Not a big problem as deep seated tumors are the target
  - A QA consideration



Lateral profile model

- Easy
- No lateral change with beam energy – transmission does not vary much
- Use profiles with 2 cm flat piece of brass for modeling of lateral fluence
    - Check for different slabs and a brass wedge



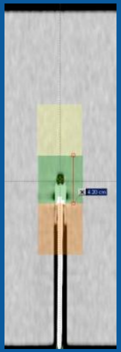


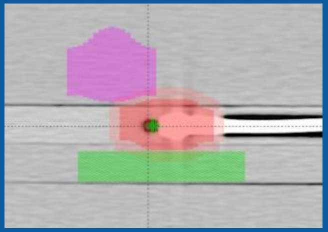
Effective Attenuation

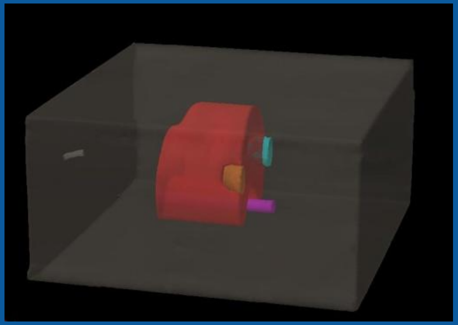
- In Pinnacle varied by varying brass density used in planning
- Cannot be perfect for all brass thicknesses, field sizes and depths – need to compromise
- 1% agreement when brass thickness ≤ 2 cm
- For 3 cm slab,
  - up to 2.8% error for fields ≥10x10cm^2
  - Up to 3.8% for 5x5cm^2

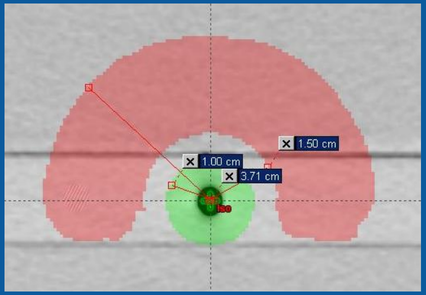
Benchmark accuracy – Ion chamber

- TG-119 plans:
  - -1.3 ± 0.9% dose to target average error
  - 1.1 ± 1.1% dose to organ at risk average error





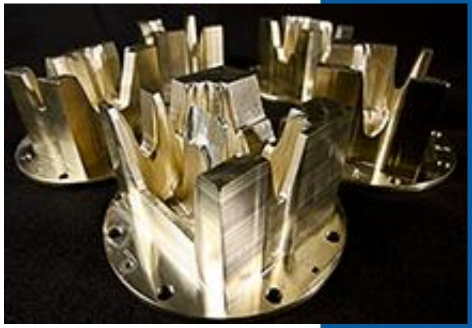




Benchmark accuracy – MapCHECK average

	MapCHECK average γ-analysis passing rate (global dose-error) (%)	
TG-119 Case	2%/2mm	3%/3mm
Mock Prostate	98	100
Multi-Target	94	100
Mock H&N	99	100
C-shape	96	100

Planning workflow



- Optimization in Pinnacle
- Export optimized fluence to .decimal software (p.d) and design the compensators based on custom fluence and known effective attenuation coefficient
- Import compensator matrix back into Pinnacle and calculate dose with compensators
- Electronically submit order to .decimal
- Perform QA

FFF in Mosaiq 2.3

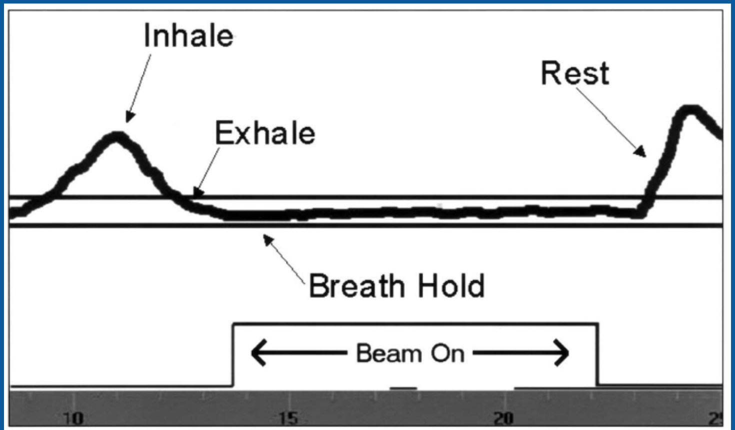
Radiation Oncology Course: 2	8/09/2012	
Rad Rx: abdomen - IMRT Compensators - x06 Dose: 4,500 cGy @ 300 cGy x 15		A 8/9/2012 RS
Site Setup		AE 8/13/2012 SLL
Simulations		
SIM2 - abdomen		A 8/9/2012
Treatment Fields		
CT - abdomen - CT		A 8/14/2012 VF
TAB - abdomen - kV Setup		
REF2 - ap abdomen - kV Setup		A 8/14/2012 VF
REF4 - rt lat abdomen - kV Setup		A 8/14/2012 VF
K - 260pancreas - 6 X FFF MLC		A 8/14/2012 VF
L - 300pancreas - 6 X FFF MLC		A 8/14/2012 VF
M - 340pancreas - 6 X FFF MLC		A 8/14/2012 VF
N - 20pancreas - 6 X FFF MLC		A 8/14/2012 VF
O - 60pancreas - 6 X FFF MLC		A 8/14/2012 VF
P - 100pancreas - 6 X FFF MLC		A 8/14/2012 VF
Q - 180pancreas - 6 X FFF MLC		A 8/14/2012 VF
Radiotherapy Fractionation	8/22/2012	

Single voluntary breath hold IMRT

- With 1400 MU/min, a beam with compensator can be delivered on a single voluntary breath hold even with hypofractionation
- Four patients have been treated at Moffitt already and more are in the planning stage

Workflow – CT Sim

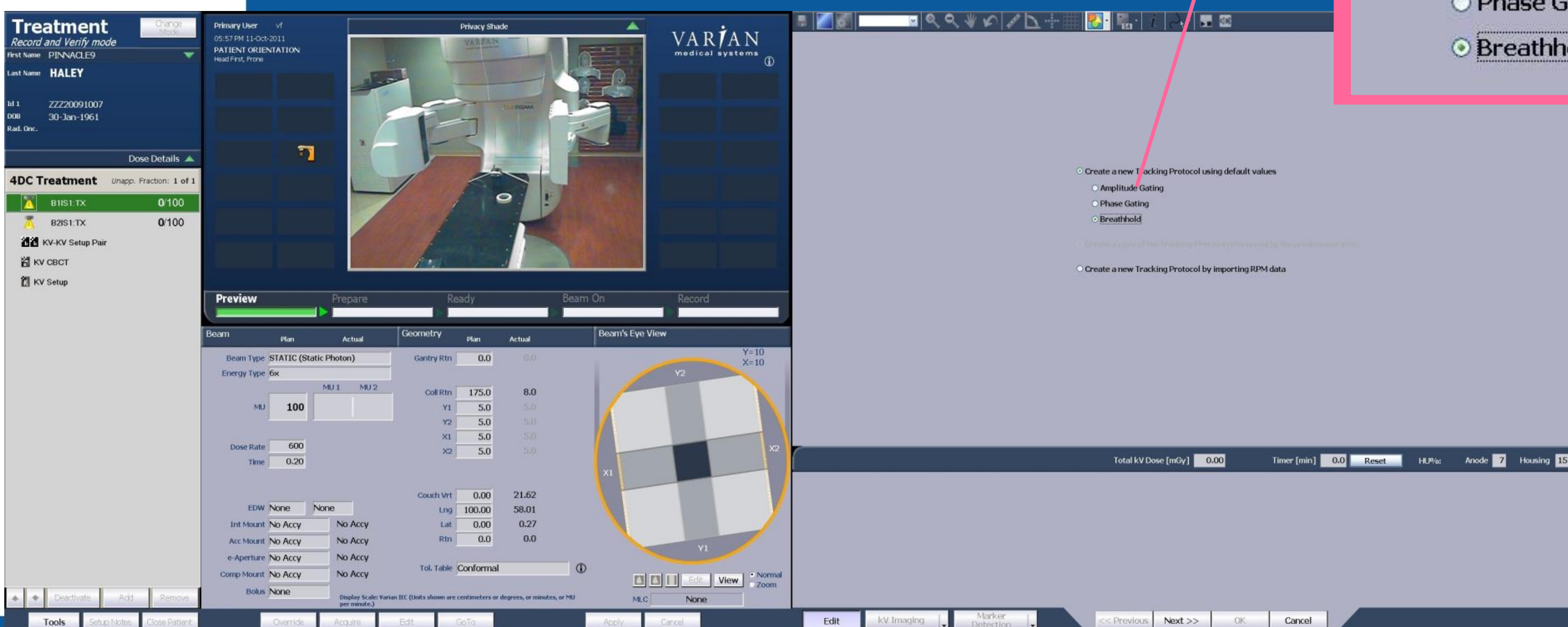
- CT simulation – scan the whole length in one moderate exhale
  - So far patient must have fiducials
  - Breath hold monitored by the bellows, the same as 4D-CT. Can just as well be done with RPM, etc.
  - Patients coached and screened for compliance. So far abdominal cases only.



Workflow - Treatment

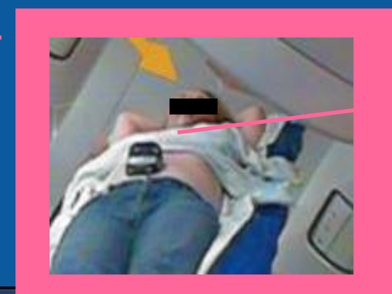
This is the workflow with Mosaiq – *ad hoc* gating. With Aria the details are slightly different

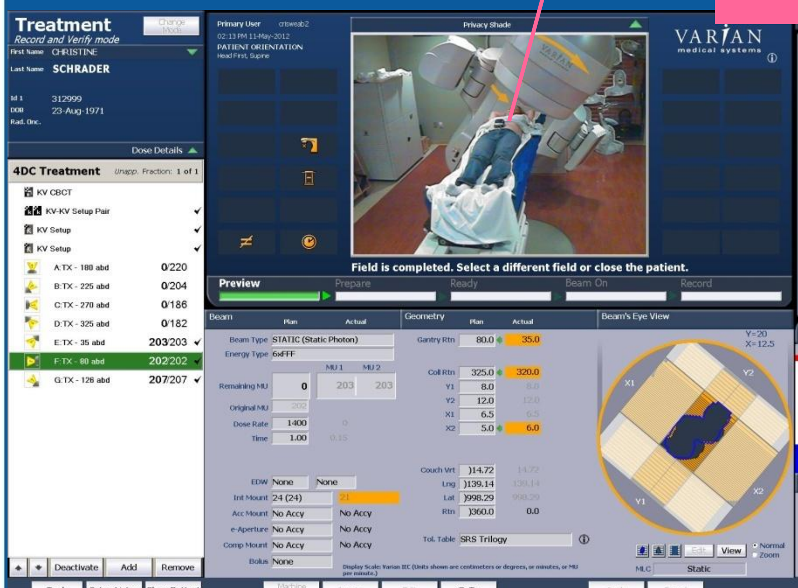
- Add Breathhold gating



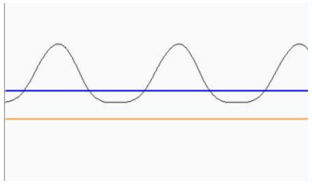
Workflow

- Place the marker block on the patient





Workflow



- Learn the breathing curve and set the exhalation threshold
- Verify the fiducials' positions by fluoroscopy
- Tell the patient to hold breath and push the button

MOFFITT CANCER CENTER

Treatments to date

Case #	Site	Total Dose (Gy)	Fx Dose (Gy)	No of beams*	Total MU
1	Pancreas	25	5	7	1404
2	Liver	50	5	7	1540
3	Liver	60	12	8	3932
4	Pancreas	45	3	7	669

*Beams with >500 MU split in 2

Case 3 Visualized

Graphics courtesy B. Nelms, PhD
(Canis Lupus LLC)