Implementing a new digital medical accelerator

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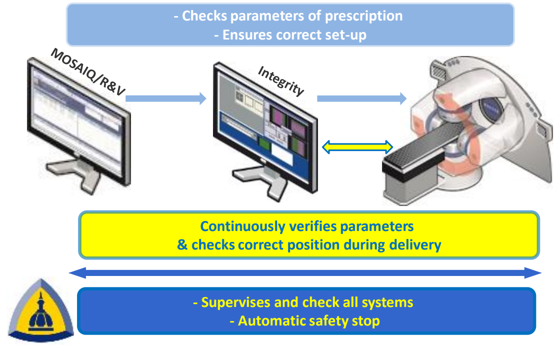
  - JW is a Founder of JPLC Associates

New Generation of Medical Accelerators

- Varian TruBeam
- Elekta evolving line of digital accelerators, from 1987
- Integrated digital control
  - Radiation – energy, delivery time, dose rate, FFF
  - New MLC --- position, speed, head rotation
  - Gantry – rotation, speed
  - Table --- position, motion *(disabled)*

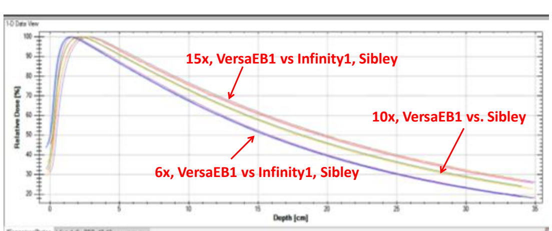
Digital Control ensures Safety and Accuracy



Implementation Issues

- The new Elekta VersaHD with Agility MLC
  – Dosimetric characteristcs
  – Geometric accuracy
  – Achieving the next level of Quality, Safety and Efficiency

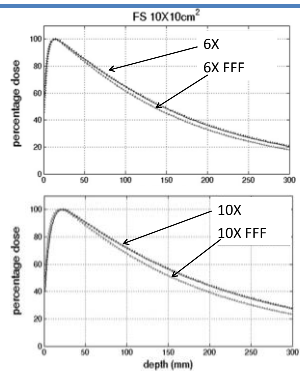
PDD: VersaEB1, Infinity1, Sibley Agility



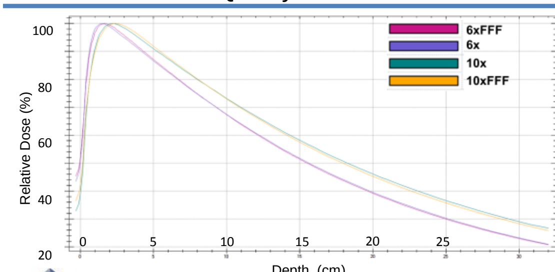
Standard depth doses (without FFF) well matched across accelerators with different heads

FFF and Beam Quality

- Flattening filter removal leads to a softer beam
  - 6 MV → 4 MV
  - 10 MV → 8 MV

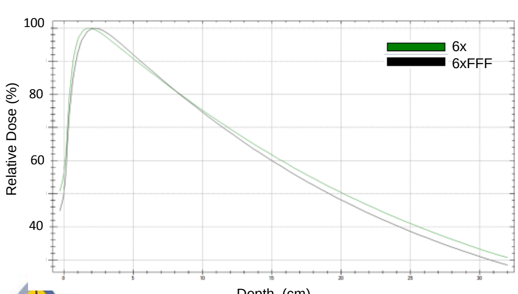


FFF and Beam Quality

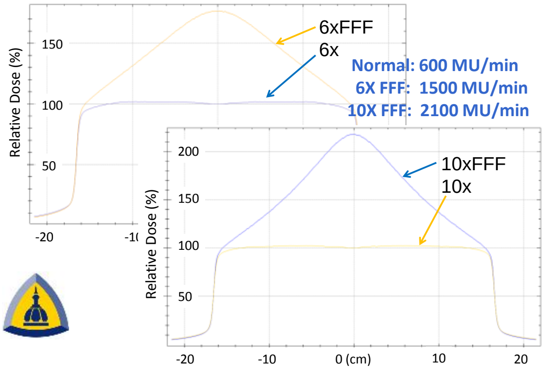


- For Elekta, the energy of the beam is tuned to achieve similar depth dose profiles for both flattened and FFF beams

Softer PDD at larger field size



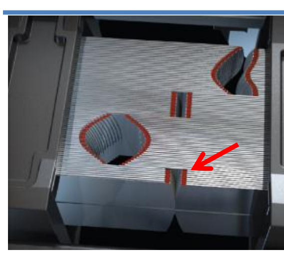
FF vs. FFF - Profile

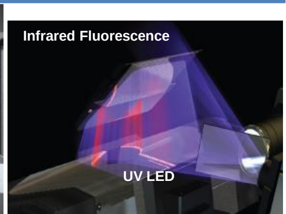


VersaHD Linac Acceptance

- Dosimetry
  - Scan data ✓
    - Photon PDD, profile (90cm SSD/10cm depth)
    - Electron PDD, profile (100cm SSD/ R85/2 depth)
  - Point measurement ✓
    - TG51 (2 individual sets to confirm output)
    - TMR measurement
    - Wedge factor
  - Dose repeatability test (at different gantry angle) ✓
  - Dose linearity test (vs. MU) ✓
  - Dose rate linearity test ✓

High Definition Agility MLC



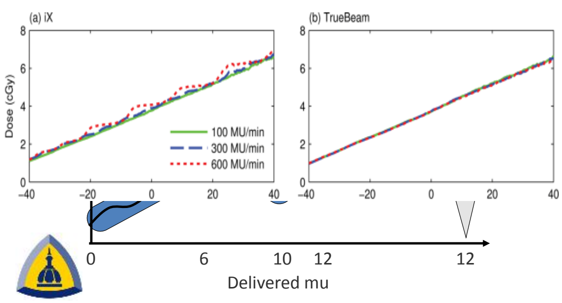


- 160 inter-digitating leaves, 5mm at isocenter,
- 3.5 cm/s leaf motion; 6.5 cm/s integrated with leaf guide
- MLC ruby reflector (UV source) – eliminates gravity effect

Integration of VersaHD and Agility

- Dose rate; leaf, diaphragm and Gantry speeds are
  - automatically selected by the control system to deliver the prescribed dose intensity and comply with machine constraints
  - changed 'on the fly' during the field delivery to minimize radiation interruption and unexpected 'beam hold offs'
  - Integrated to achieve minimum delivery time and optimal plan quality

Automatic dose rate selection: Elekta and TruBeam

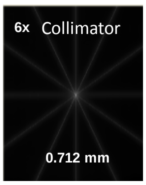


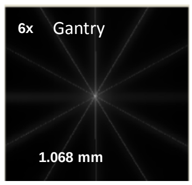
The Congruence and Integrity of Radiation/Mechanical Setup

- *The fundamentals of accurate treatment,*
  - *Initial alignment of radiation isocenters with mechanical setup --- the birthmark*
- Traditional setup
  - Installers: setup to a mechanical isocenter;
  - Physicists: treat to the radiation isocenter
- Traditional tests
  - Mechanical measurements
    - Gantry; Collimator, Table, …. Readout,..etc
    - Light field Vs. Radiation field congruency,
    - …..

Traditional Evaluation of Radiation Isocenter(s)

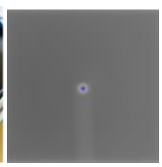
- For each energy, each mechanical component is characterized by its own radiation isocenter; within a 1 mm "circle of confusion"
- *Inconvenient Truth: radiation isocenter(s) is typically accepted at one single energy for the major vendors.*
- The physicist should measure and tune the radiation isocenters for all x-ray energies

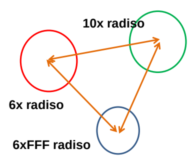




No GT information

VersaHD: BB tool with EPID
Alignment of the multiple radiation isocenters with EPID



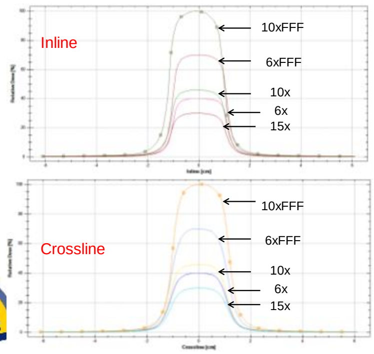


- Determine the radiation isocenter based on EPID images the BB with a combination of 4 cardinal gantry & 2 collimator angles for 6X (<0.1 mm accuracy).
- Compare the radiation isocenter of other energies (10x, 15x, 6xFFF, and 10xFFF) with 6x.

Alignment results with adjustment at acceptance

(mm)	6x	10x	15x	6x FFF	10x FFF
AB (x) toward A	0.05	0.05	0.01	0.04	0.07
GT (y) toward T	0.03	0.12	0.23	0.16	0.99
UP-down (z) up	0.01	0.07	0.1	0.03	0.08
3D shift w.r.t 6x	0	0.11	0.28	0.19	0.96

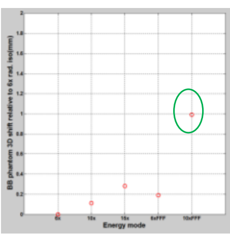
Radiation isocenter offset on beam profiles



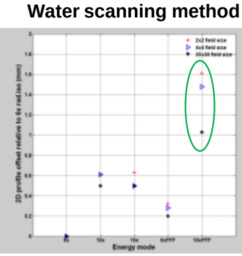
More obvious with small (2x2 cm^2) at 10cm depth

Radiation Isocenters before beam tuning

EPID method



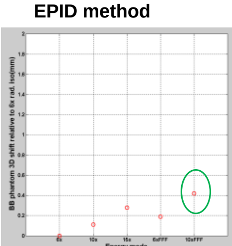
Water scanning method



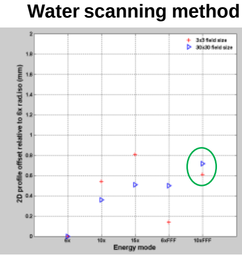
The 10xFFF radiation isocenter deviates from other x-ray energies

Radiation Isocenters after beam tuning

EPID method



Water scanning method



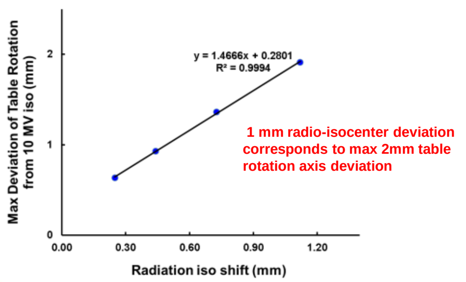
All the radiation isocenters are within 0.4 mm using EPID method and 0.8 mm using tank.

Table isocentricity is a function of gantry isocenter

Energy	Max Table Isocenter Deviation
6x	0.42 mm
10x	0.63 mm
15x	0.54 mm
6xFFF	0.37 mm
10xFFF	0.91 mm

Baseline For Monthly QA

Table isocentricity is a function of gantry isocenter



The shift between radiation isocenters of 6 and 10 MV linearly correlates with the deviation of table rotation axis from 10 MV radiation isocenter

Winston-Lutz Test

- Always a final end-to end IGRT run (to include RTP)
- Overall position accuracy taken into account gantry, collimator and table movement
- Test was performed with EPID
- Baseline

1.1	T0G0	1.2	T0G0C180
2.1	TOG0C90	2.2	T0G0C270
3.1	T0G90	3.2	T0G90C180
4.1	T0G180	4.2	T0G180C180
5.1	T0G270	5.2	T0G270C180
6.1	T0G225	6.2	T0G225C180
7.1	T90G225	7.2	T90G225C180
8.1	T45G340	8.2	T45G340C180
9.1	T315G20	9.2	T315G20C180
10.1	T270G135	10.2	T270G135C180

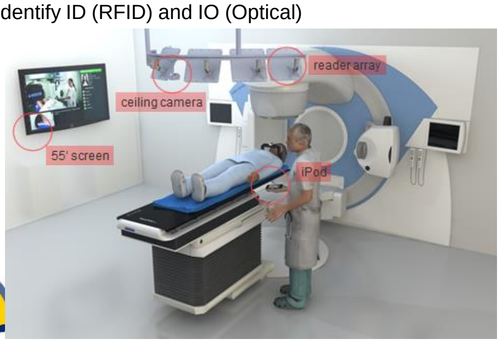
Energy	Settings with Maximum Deviation
6x	1.20 mm @ T0G0C90 & T0G0C270
10x	1.39 mm @ T0G0C180
15x	1.06 mm @ T0G0
6xFFF	1.36 mm @ T0G0C0
10xFFF	1.03 mm @ T90G225C180

Conclusions

- The new generation of digital accelerators offers improvement in quality, safety and efficiency to deliver radiation treatment
- The acceptance process should be used to establish the "best" baseline performance of the accelerator
- The increased capabilities also imply increased QA tasks
  - New generation of QA devices and methodologies are needed
- The next level of quality, safety and efficiency needs to consider the entire delivery process in addition to the performance of the machine

Beyond the digital accelerator

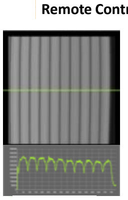
- Identify ID (RFID) and IO (Optical)

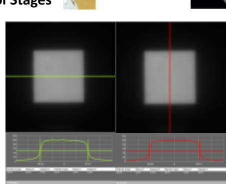


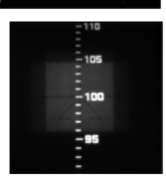
New QA tools (minimize room entry)


Remote Control Stages


Unified QA

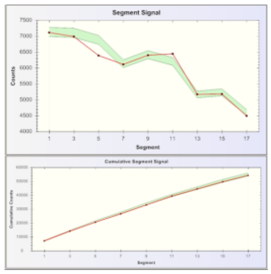

MLC QA


Radiation QA



Mechanical/Optical QA

iQM --- Integral Quality Monitor (from PMH and iRT)

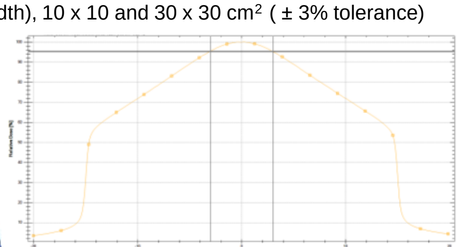


An integral quality monitoring system for real-time verification of intensity modulated radiation therapy. Islam et al. Med. Phys. 36, 2009; US patent 8119978

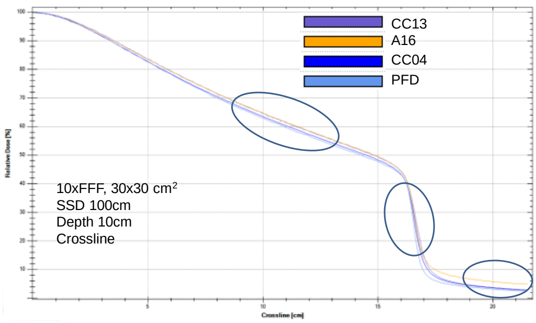
Thank you !

Photon Beams – Profile (FFF beam)

- Symmetry is defined the same the FF beam.
- Specify relative dose at different points of measurement (20%, 50% and 80% of the half field width), 10 x 10 and 30 x 30 cm^2 (± 3% tolerance)



Other Issue: Choice of Detector for FFF Beams



Other task: VMAT Delivery Test

HN, Coronal, 3%/3mm DTA criteria, AD passing rate: 97.1%