Introduction

Previous talk already describe the data collection and the clinical validation

- Elekta FFF Beam Characteristics
- Pinnacle Treatment Planning commissioning Tips
- Discussion of Clinic Implementation and the Future Directions

Electron Setup

Currently FFF is not available.
approximate release date: early 2013
6 and 10 MV dose rate ~1400 MU/min (open field)
Flattening filter function

- Aim is to produce a uniform intensity
- But in doing so it
  - Attenuates central axis dose to ~50%
  - Creates the largest source of scattered radiation in the head
  - Changes the beam spectrum across the field

Driving force for FFF: SBRT – hypofractionation treatment delivery to reduce the treatment time

FFF Beam Characteristics

- Simpler LINAC physics
- Higher dose rate (easy for LINAC to produce high dose output)
- Output calibration (chamber response)?
- Non-flat beam
- Same spectrum at the different off-axis point=> slow variation for the depth dependent profiles
- Easy to obtain symmetry profiles
- What about the field size definition?
- Beam quality reduced after remove the FF
- No extra-focal radiation contribution due to the flattening filter (ie. Minimum head scatter variation for larger field size)
- Reduced head leakage radiation
- Sharper field edge

Dose rate effects and Calibration

- Dose rate DOUBLED
  - 2.1 times open
  - 1.8 times wedge
- Treatment time halved for open field
- Measured dose still linear & reproducible
- Output calibration: Pion increase, but not much
Open field profiles at d= 10 cm

Small fields – 4x4 cm

FF vs. FFF profiles, depth dependent
FS=20x20 cm²
Wedge Profiles

Figure 8. Comparison of measured wedge profiles for a 20 x 20 cm² field, normalized at d_max. Profiles depths are at 15 and 100 mm.

Open field profiles: symmetry

Linear regression: abs(L_slope) = abs(R_slope)

ΔΦ

2R variation

Δr

Bf variation

Field size definition

Derivative of profile Relative profile

Field width
Beam quality reduced

Figure 4. Depth doses for a 10 x 10 cm² field at 100 cm SSD. Lack of beam hardening is seen as an energy decrease to approx. 5 MV.

Surface Dose

Figure 6. Variation of surface dose (at 3 cm depth) with aperture square normalized to a 10 x 10 cm² field. Measurements to nearest ratio ± 1.02 with the following error ± 1.37 million, ± 1.37 million.

Sc Scp

40x40 cm² Sc = 1.05 (FFF), 1.045 (FF) due to profile diff. 100 cm SSD, d=dmmax
Collimator exchange effect

- Film results vs SSD, $d_{max}$
  
<table>
<thead>
<tr>
<th>SS</th>
<th>FF in</th>
<th>FF out</th>
<th>Diff</th>
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<tbody>
<tr>
<td>5</td>
<td>4.1</td>
<td>2.8</td>
<td>-1.3</td>
</tr>
<tr>
<td>10</td>
<td>3.7</td>
<td>2.8</td>
<td>-0.9</td>
</tr>
<tr>
<td>15</td>
<td>3.6</td>
<td>3.0</td>
<td>-0.6</td>
</tr>
<tr>
<td>20</td>
<td>4.2</td>
<td>5.8</td>
<td>+1.6</td>
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</table>

- Beam edge is sharper
- Dose outside field lower

Leakage

Leakage radiation (% of reference reading)

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<tr>
<th>Position</th>
<th>Filter in</th>
<th>Filter out</th>
<th>% Decrease</th>
</tr>
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<tbody>
<tr>
<td>5 cm G</td>
<td>0.012</td>
<td>0.006</td>
<td>42.2</td>
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<tr>
<td>5 cm T</td>
<td>0.005</td>
<td>0.0029</td>
<td>45.9</td>
</tr>
<tr>
<td>5 cm A</td>
<td>0.018</td>
<td>0.0079</td>
<td>55.4</td>
</tr>
<tr>
<td>5 cm B</td>
<td>0.019</td>
<td>0.0072</td>
<td>55.4</td>
</tr>
<tr>
<td>10 cm G</td>
<td>0.013</td>
<td>0.0034</td>
<td>66.6</td>
</tr>
<tr>
<td>10 cm T</td>
<td>0.011</td>
<td>0.0032</td>
<td>66.6</td>
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<tr>
<td>10 cm A</td>
<td>0.018</td>
<td>0.0079</td>
<td>55.4</td>
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<tr>
<td>10 cm B</td>
<td>0.025</td>
<td>0.0041</td>
<td>76.0</td>
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</table>

Average decrease 58.1%

Penumbra

- Beam edge is sharper
- Dose outside field lower
MLC transmission

FFF TPS benefits
- Azimuthal symmetry profiles -> beam model accuracy increase
- Less variation of output factor -> beam model accuracy increase
- Same spectrum -> simplify beam model -> dose calculation accuracy increase

TPS modeling tips
- Spectrum
- Spectral off-axis softening factor
- Off-axis modeling
- Extra focal radiation
- Calculated output factor
It is possible to adjust the beam quality the same as with FF for 10x10 cm²; however, the 30x30 cm² FDD will not be the same due to the profile differences between FF vs. FFF.

Spectrum

Spectrum should not expect to be the same as FF beam even with the same QI for 10x10 fields.

Spectral off-axis softening Factor
Flattening Filter Attenuation

off-axis profile modeling

Flattening Filter Scatter Source

extra-focal radiation

Minimum contribution from extra focal radiation

Scp TPS correction factors

Calculated output factor is largely depend on off-axis intensity and the extra-focal radiation source
FFF Clinical implementation pro and con

Pro:
- Dose rate x2+
- SBRT (IMRT, Dynamic Arc, conformal arc) -> fast delivery
- Standard dose (≤2Gy or less) slightly better performance
- Better normal tissue sparing due to FFF profiles
- Head leakage radiation reduce dramatically

Con:
- Emergency patient treatment with large field length, a simple point calculation will not be adequate

What is the future?

- FFF + FF photon beam Linac: FF beam for the emergency case and FFF for everything else.
- Or FFF only machine with preplan for emergency patient care provided by TPS vendor, similar to dynamic wedged concept.

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