Novel Techniques in Proton Therapy

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Need for novel techniques in proton therapy:

Do not treat tomorrow’s patients with yesterday’s proton technology!

The Five High’s:

- Higher quality
- Higher accuracy
- Higher flexibility
- Higher intensity
- Higher energy

...and One Low:

- Low Price

  => Reduction of size
high quality of dose delivery
Dose delivery techniques: lateral

Scatter technique

Scatter system

Collimator, bolus

Pencil beam scanning

Best dose distribution
Scatter – Homog. Spot – IMPT

Scattered beam

Spot scanning

IMPT

1 field

1 field

1 field

3 fields

3 fields

3 fields

(Tony Lomax)
high accuracy of dose delivery
Possible solutions:

- Gating
- Adaptive scanning (tumor tracking)
- Fast rescanning

organ / tumor motion

Organ motion

Respiration Signal

Expiratory

Inspiratory

Extracted Beam
PSI Gantry-2: fast 3D scanning

David Meer
Christian Hilbes
Silvan Zenklusen
(PSI)
high accuracy: IGPT

NOTE

Integrating a 1.5 T MRI scanner with a 6 MV accelerator: proof of concept

B W Raaymakers¹, J J W Lagendijk¹, J Overweg², J G M Kok¹, A J E Raaijmakers¹, E M Kerkhof¹, R W van der Put¹, J Meijsing¹, S P M Crijns¹, F Benedosso¹, M van Vulpen¹, C H W de Graaff³, J Allen³ and K J Brown³

High flexibility in techniques

- Flexible in dynamics of treatment
- Flexible equipment and control:
  an investment for a long (>25 yrs) period:
  “future proof”
  „upgradeable“
250 MeV proton cyclotron at PSI (Varian)

- Proton source
- Superconducting coils => 2.4 - 3.8 T
- ~80 kV on 4 Dees
- ACCEL
- 180 kW
- 90 tons
- 3.4 m
- 1.4 m
**Max. intensity** set by:
proton source

Deflector plate:
sets intensity
- within 50 µs
- 3% accuracy

Deflector voltage
Beam intensity
Time (ms)
Advantages of a cyclotron

=> a cyclotron provides max. flexibility:

- continuous beam
- any intensity
- very fast adjustable intensity
- accurate intensity control
- great reliability

+ range change of 5 mm < 50 ms

(with fast degrader and good magnets + power supplies)

Needed for future upgrades
Dose delivery techniques: Depth

At PSI:
- Carbon wedge degrader
  238-70 MeV

> fast treatment
> fast room switching

250 MeV cyclotron

All following magnets: 1% field change in 50-80 ms
High flexibility: fast E-change

Vary energy at accelerator: synchrotron

Vary energy at each spill:

Beam energy

Vary energy during a spill:

Hitachi Ltd

Proton source + injector

Iwata et al., IPAC’10, Kyoto, Japan MOPEA008
High flexibility: fast E-change

Cyclotron-Linac combination

30 MeV cyclotron +
isotope production
targets

+ Energy set per pulse
+ Only beam accelerated when needed
- Pulsed beam at low rate (200 Hz)
- Dose per pulse accuracy?

High beam intensity
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high intensity & high flexibility

parallel, independent treatment rooms!

PSI beam splitter

1-1.5 μA

230-250 MeV

splitter

Dedicated beam stopper

Dedicated degrader

Gantry 1

Gantry 2

Gantry 3

HV electrode

septum

PSI beam splitter
High energy

A possible facility upgrade
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Gantry with 20% stronger field

230 or 250 MeV cyclotron

energy selection

230 or 250 MeV

7m Linac

350 MeV

Linac based on existing TERA design of CCL linac
High energy for:
- proton radiography:
- treatment of small lesions
- sharpen edge of dose distrib.

Range determination by direct stopping power measurement

Proton range radiograph (Uwe Schneider, PSI)
ImPulse project PSI:

Linac for boosting from 250 to 350 MeV

250 MeV cyclotron

Linac location if gantry-3 accepts 350 MeV

In collaboration with TERA
Reduction of size
Decrease accelerator size

Solution:
Increase magnetic field
=> Smaller orbit radius
**Cyclotron**

**Cyclotron works while:** $T_{\text{circle}}$ independent from radius  
(particles move in pace with $V_{\text{dee}}$)

**However:** at very strong magnetic fields:
- $V_{\text{dee}} \sim \frac{C}{r}$
- Magnetic field decreases with radius

$\Rightarrow T_{\text{circle}}$ increases with radius  
$\Rightarrow$ particles lose pace with frequency of $V_{\text{dee}}$ (RF).

**Remedy:** decrease $f_{RF}$ with radius:  
**synchro-cyclotron**

$\Rightarrow$ pulsed beam (1 kHz)  
$\Rightarrow$ strong magnetic fields possible

$\Rightarrow$ Smaller machines!!
Synchro-Cyclotron

8-10 T  250 MeV Synchro-cyclotron on a gantry

- First beam extracted in May 2010
- No beam analysis => distal penumbra = 5.7 mm at all E
- Scattering only
- Beam quality (penumbra, dose rate), Neutrons?

- Dose Rate: 2-4 Gy/min (max-10Gy/min)
- Head leakage measured well below 0.1% (Q=10)
Synchro-Cyclotron

5.6 T 230 MeV Synchro-cyclotron with a gantry

SC 5.6T 230 MeV synchro-cyclotron

Degrader

Beam analysis

2D - PBS

20x25 cm² field

- Conservative design parameters
- Beam analysis and Pencil Beam Scanning
- Conceptual design ready

? Beam quality (penumbra, dose rate)
- Pulsed (1 kHz)
Dielectric Wall Accelerator

**Basic Idea:** pulsed very high electric fields (100 MV/m)

Caporaso et al, Nucl Instr Meth B 261 (2007) 777

- ~4000 electrodes, each with 2 HV switches (25 kV)
- 2 ns pulses with 100mA protons at 10 (…50?) Hz

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Novel Techniques in Proton Therapy

Many promises, nice brochures

But: still in development....

needed: reached:
100 MV/m  20 MV/m
2.5 m    4 cm

Prototype 150 MeV (4m) planned: end 2014

— Pulsed beam
— Low duty cycle (10 Hz)
— dose accuracy?
— Overall dose rate?
Compact synchrotron

Advantages
Light, relatively cheap,
low activation

HOWEVER
Not smaller than a cyclotron facility
Details on operation are not given
Laser accelerated protons

- Laser light
  - pushes electrons out
- Electric field from electrons
  - pulls protons out of foil

See talk of L. Laschinsky

thin foil, doped with hydrogen
Great developments at companies

But: be critical at company bla bla bla bla…:

Typical announcements at milestone:

”Proton Acceleration Demonstrated”

“We plan to have an integrated, fully-functional prototype accelerator system in 3 months time.“

„We will extract clinical quality beam and demonstrate full intensity-modulated proton therapy (IMPT) capability in the next 12 months.“

„Our first shipment to a clinical site is planned for the first half of 2009 2010 2011 2012 2013.”
New (i.e. “cheap”) systems

What are the compromises?

Is really Better?

1) at least the same quality as we have now?
   and, if yes:
2) how reliable?
3) when available?
4) what are the advantages (size, costs, quality?)
Thank you