Integration of new (motion resolved) imaging capabilities in proton therapy

Tony Lomax for the CPT team

4D workshop, Dresden, 27 November 2015
Imaging motion

• 2/3D imaging
• 4D imaging
• 5D imaging
• Integration in proton therapy
Imaging motion

- 2/3D imaging
- 4D imaging
- 5D imaging
- Integration in proton therapy
2/3D imaging = 1/2D imaging + motion
2/3D imaging

X-ray fluoroscopy

Ye Zhang, PSI

Integration of new imaging capabilities in proton therapy
Optical systems

Figure 2

Varian RPM

Vision RT
2/3D imaging

EM and US systems

Varian Calypso

Integration of new imaging capabilities in proton therapy 4D workshop, 27th November 2015
Imaging motion

• 2/3D imaging
• 4D imaging
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• Integration in proton therapy
4D imaging = 3D imaging + motion
4D imaging

4DCT – is it good enough for protons?

Probably not, at least not for dose and range calculations

Images courtesy of Dan Low
Integration of new imaging capabilities in proton therapy

4D workshop, 27th November 2015
4D-CBCT – is it any good for protons?

Very doubtful in this form...

Yan et al 2014, Med Phys 41:071903
4D-CBCT – is it any good for protons?

Yan et al 2014, Med Phys 41:071903

Integration of new imaging capabilities in proton therapy
Imaging motion

- 2/3D imaging
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4D imaging

5D imaging = 3D imaging + multiple motions
5D imaging. The UCLA approach

- Acquire 25 fast, multi-slice helical scans together with breathing surrogate
- ~ 1.5-2.5s per scan
- Total acquisition – 140s (2.5 Minutes)
- Results in 25 positions per voxel
- Use to build 4D model

\[
\tilde{X}(v, f) = \tilde{X}_0 + \alpha(\tilde{X}_0)v + \beta(\tilde{X}_0)f
\]

Thomas et al 2014, IJROBP 89:191-198
5D imaging. The UCLA approach

- Artefact free imaging
- Reconstruction of arbitrary phases
- Reconstruction of variable breathing patterns?
5D imaging. The Swiss approach

5D MRI

Von Siebenthal et al 2007, PMB 52:1547-1564
Integration of new imaging capabilities in proton therapy

Zhang et al 2013 PMB 58:8621-8645

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5D imaging

5D imaging. The Swiss approach

5D reconstructed motion from X-ray fluoroscopy surrogate

Accuracy of reconstructed motion

Zhang et al 2013 PMB 58:8621-8645

Integration of new imaging capabilities in proton therapy

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Imaging motion

- 2/3D imaging
- 4D imaging
- 5D imaging
- Integration in proton therapy
Integrating 4D monitoring

Gantry based CBCT for protons

Varian pictures courtesy of Michael Schillo, Varian Particle Therapy
Integrating 4D monitoring

In-room CT

PSI gantry 2

OncoRay, Dresden

Integration of new imaging capabilities in proton therapy

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Integrating 5D monitoring

5DCT for protons?

The Swiss approach

Pre-treatment 5D MRI imaging and patient specific model

On-line surrogate

Prediction of 5D motion

Integration of new imaging capabilities in proton therapy
Integrating 2/3D monitoring

X-ray fluoroscopy

E.g. Varian ProBeam (and all others)

BEV imaging (PSI Gantry 2)
Optical and EM surrogates

**Optical system**
- Limited visibility of markers
- But at least 3 visible in worst-case scenario (shown)

**EM system**
- Severe distortion of position read-out
- Localization errors of 2-3cm

Giovanni Fattori et al (PSI), Manuscript in preparation and see poster
Integrating 2/3D monitoring

Proton imaging as a surrogate?

Abdel Hammi, PSI

Integration of new imaging capabilities in proton therapy

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Integrating 2/3D monitoring

Proton imaging

Abdel Hammi, PSI

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Integrating 2/3D monitoring

Proton BEV fluoroscopy?

Abdel Hammi, PSI
Summary

• Imaging in proton therapy is beginning to catch up with conventional therapy

• In-room imaging (2-4D) is becoming available (in-room CT, CBCT)

• 5D CT could be incorporated if fast scanners are provided on rails

• 5D imaging, in-form of models and on-line surrogates, is being developed

• But what about direct MRI guidance?
MRI guided proton therapy?

Raaymakers et al 2008 PMB 53:5615-5622
Moteabbed et al 2014 Med Phys 41: 111713

Integration of new imaging capabilities in proton therapy

4D workshop, 27th November 2015
6D imaging (multiple modality 5D)?

Tony Lomax and Marco Schippers 2010 (PSI)
Integration of new imaging capabilities in proton therapy

The PSI Proton therapy team

Thanks for your attention