AAPM 2019 JUL 14–18
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Spot-scanning Proton Arc therapy (SPArc) – from a concept to reality

Xuanfeng (Leo) Ding, Ph.D., DABR
Lead Medical Physicist, Proton Beam Therapy
Assistant Professor, William Beaumont School of Medicine,
Oakland University
July 15th, 2019

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Disclosures:

- The SPArc research project is supported by:
  - Ion Beam Application S.A.
  - Beaumont Herb and Betty Fisher Research Seed Grant Award
- I do have a patent related to the technique and the patent is licensed to IBA

Table of Contents

The start of the journey

- When I was a resident at UPenn 2012…
  - I had no idea of the proton beam therapy
  - I had very limited clinical experience in X-ray

Why Proton doesn't have a rotational treatment technique like VMAT?

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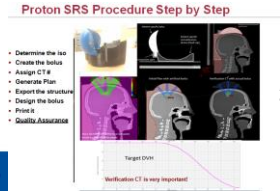
The first try with 3D printing bolus

- Dr. Kevin Teo: "Shall we do some projects with 3D printer?"
- Leo: "Great idea! But where is the printer?"
  - Solid water
  - Clam shell replace the stainless steel one in photon
  - How about patient specific bolus?



First 3D printed bolus to compensate the range difference for passive-proton arc therapy

1st place at Young investigator symposium in AAPM clinical annual meeting 2014

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Dosimetric limitations?

- Uncertainties ➡ 3D/4D Robustness optimization (Liu et al) RaySearch Raystation Varian Eclipse 13
  - Range, setup, motion .etc.
- Long delivery time ➡ Delivery Efficiency engine (Cao et al, Van de Water et al)
  - Limits the beam number per fx
- Larger Penumbra (Spot size) ➡ Dynamic Collimation system (Hyer et al, U of Iowa)

Proton Arc Therapy

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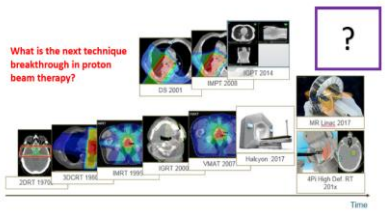
The next technique breakthrough?



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The history of Proton Arc Therapy

- Sandison et al. did a chestwall phantom irradiation using passive-scattering technique in 1997
- Joseph Dessy, Ryan Flynn and Miao Zhang and Thomas R Mackie et al. proposed distal end tracking (DET) method.
- Seco et al. in 2012 explored the dosimetric advantage of using proton arc therapy for lung SBRT

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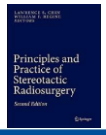
Do we need proton arc therapy?

- *Principles and Practice of Stereotactic Radiosurgery* by Lawrence S. Chin and William F. Regine 2015 p 87. Proton arc therapy is **not feasible nor is it necessary** to generate conformal plans.
- Dr. Yu: "intensity modulated proton arcs **would be harder, if not impossible,** to achieve with the current spot scanning technology".
- Dr. Paganetti:"The lack of intensity modulated proton arcs is not a limitation because the technique **is not even necessary** for protons given the advanced dose shaping capabilities and small spot sizes"



Photon radiotherapy has reached its limit in terms of catching up dosimetrically with proton therapy

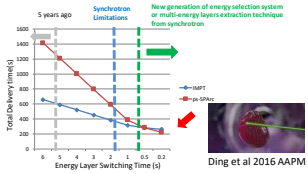
Harald Paganetti, Ph.D.
Department of Radiation Oncology, Massachusetts General Hospital and Harvard Medical School, Boston, Massachusetts 02114
(Tel: 617-726-3947; E-mail: hpaganetti@mgh.harvard.edu)

Cedric X. Yu, D.Sc.
Department of Radiation Oncology, University of Maryland School of Medicine, Baltimore, Maryland 21201-1595
(Tel: 410-328-0324; E-mail: cyu002@umaryland.edu)

Colin G. Orton, Ph.D., Moderator

(Received 2 June 2016; accepted for publication 5 June 2016; published 7 July 2016; corrected 8 July 2016)

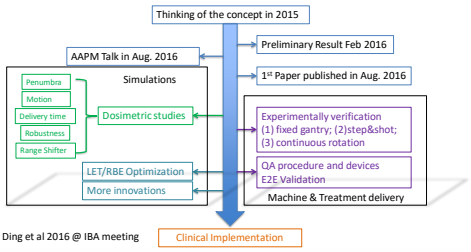
Proton Treatment Delivery Time



Ding et al 2016 AAPM

Hypothesis

- **Dosimetric Plan quality:**
  - More freedom of optimization = better plan quality (conformity)
  - More beam angles = less dosimetric impacts on the range uncertainty
- **Treatment efficiency**
  - Layer switching is faster and faster = Proton arc with more energy layers is clinical feasible
  - Finish the treatment with one arc = improve the workflow efficiency
- **Optimization and calculation burden**
  - Iterative optimization approach to relieve the calculation burden = 360 degree proton arc sampling frequency optimization feasible
- ***Reduce acute toxicity of organ abutting the target***
- ***Expand the proton beam therapy application to more disease sites or indications***
- ***Significantly increase the proton facility daily treatment capacity***



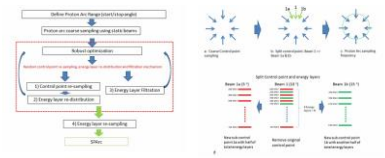
Ding et al 2016 @ IBA meeting

Spot-scanning Proton Arc Therapy

- Gantry/Couch continuous movement while
  - Delivering proton beam
  - Scanning proton spots
  - Switching energy layers
- Goal: Make particle therapy treatment more efficient, more robust, better dose conformity

SPArc – Planning Optimization Algorithm

Use **iterative optimization approach** to increase the control point sampling frequency to a desired arc delivery sampling frequency

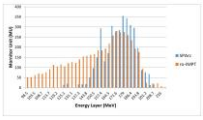


Ding & Li red journal 2016

SPArc – Delivery Optimization Algorithm

- Reduce the low weighting energy layers and spots
- Energy switching sequence sorting and optimization

Energy Layers and MU distribution



Ding et al. Acta Oncologica 2019

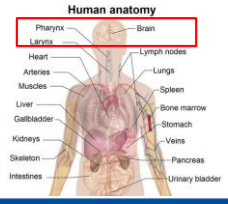
Deliver sequence optimization

Ding et al. PTCOG 2018

Spot-scanning Proton Arc Therapy

Dosimetric Studies

Dosimetric Studies



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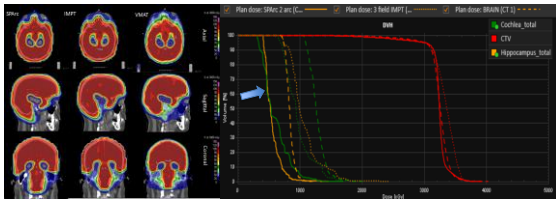
Whole Brain Radiotherapy with Hippocampal and cochlea sparing



Ding et al. Acta Oncologica 2019

Figure: A representative CT slice of a patient contours and dose distribution and DVHs

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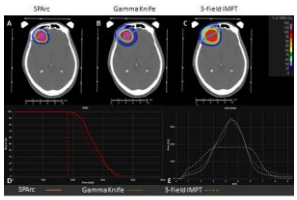
Brain SRS



Ding et al. PTCOG 2017

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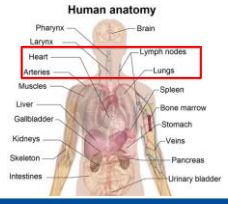
Dosimetric Studies



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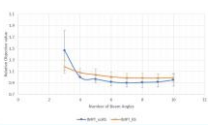
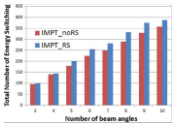
Do we need REALLY range shifter?

TECHNICAL NOTE Open Access

Redefine the role of range shifter in treating bilateral head and neck cancer in the era of Intensity Modulated Proton Therapy

Xuanfeng Ding, Xiaoqiang Li, An Qin, Jun Zhou, Di Yan, Peter Chen, Chinnaiyan Prakash, Craig Stevens, Rohan Deraniyagala, Peyman Kabolizadeh





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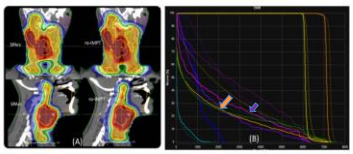
Bilateral HNC



About 30% reduction in the parotid mean dose

Figure 1 (A) Dose distribution comparison between SPArc and ro-IMPT for patient #3. B) DVH evaluation, SPArc (solid line) and ro-IMPT (dotted line);

Gang et al. (in revision)

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Bilateral HNC

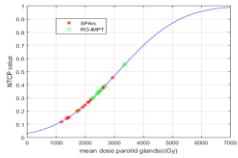

Fig 5. Normal tissue complication probability (NTCP) model for parotid salivary flow (solid curve). The NTCP value denotes the probability of a reduction in salivary flow to <25% of the pretreatment flow at ≤ 6 months after radiotherapy.

Gang et al. (in revision)

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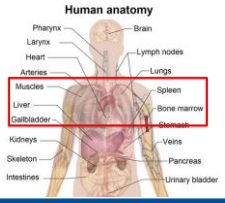
Dosimetric Studies



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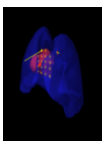
Interplay effects for proton therapy

- The motion of the beam could interfere with the motion of target
- May result in distortion of the planned dose distribution, local over- and under- dosage
- One of the major concerns for treating lung cancer with scanning beam proton



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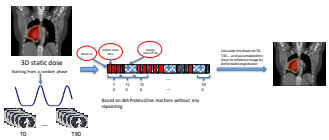
Single-fraction 4D dynamic dose



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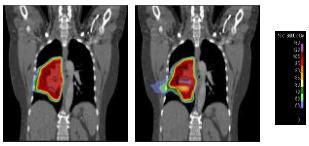
Single-fraction 4D dynamic dose



Patient 6, ITV volume of 402cc, S-I motion of 1.2 cm Li et al. Radiation Oncology 2018

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Effectiveness of mitigating Interplay Effect

A digital target 4DCT imaging set

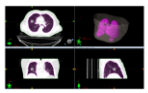

Figure 1. An example of a digital phantom. The pink sphere contour represents the target gross target volume (GTV).

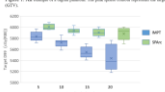

Figure 2. Sing fraction dynamic dose for target D99 along with motion amplitude.

Compared to the volumetric repainting technique

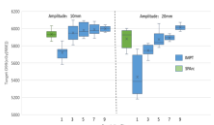

Figure 3 Sing fraction dynamic dose for target D99 along with repainting times for the case with target motion in SI direction 10mm and 20mm.

Gang et al. Young Investigator award in PTCOG 2019

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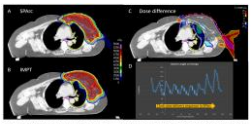
Breast Cancer

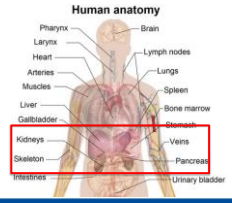
- Limited field size of a compact gantry
  - 20cm x 24 cm
  - Multi-field matching and multi-iso shifts takes significant time



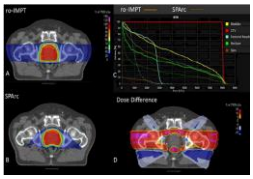
Single iso
Easier clinical workflow
Better conformality
Better Heart and lung sparing

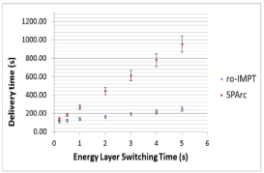
Ding et al. ESTRO, 2019

Dosimetric Studies



SPArc for prostate cancer

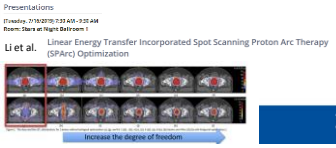




Ding et al. Acta Oncologica (2017)

SPArc could offer more treatment options

- SBRT/SRS
- Mobile tumor treatment
- Dose escalation
- LET/RBE painting



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Have we reached dosimetric limitation yet?

- Let's spin our gantry first

PTCOG 2018

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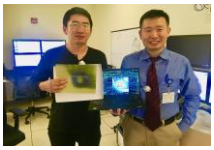
On August 29th 2018, 2:30am EST



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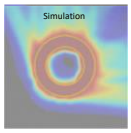
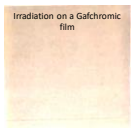
World first SPArc Treatment Delivery at Beaumont PTC on IBA ProteusONE system

Target volume: 123 cc
Target diameter: 9.5 cm
Target thickness: 3 cm

Target dose: 6 Gy
Number of spots: 2624
Number of energy layers: 58

Delivery time: 4m27'
Minimum energy: 100 MeV
Maximum energy: 166 MeV





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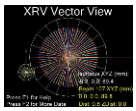
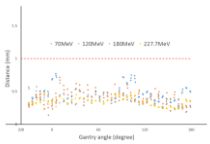
Basic Proton Arc Delivery Characteristics 1

- Central spot position check
  - Energy range (70-227.7MeV)
  - 2D cone shaped scintillator detector
  - Tolerance: 1mm





Li et al. Green journal 2019

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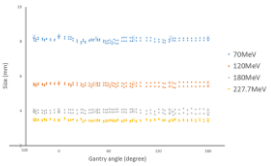
Basic Proton Arc Delivery Characteristics 2

- Central spot profile check
  - Static vs Arc delivery
  - Energy range (70-227.7MeV)
  - 2D scintillator detector with a gantry mount
  - Tolerance: 1.5%



Li et al. Green journal 2019

Presentations

(Tuesday, 7/16/2019) 7:30 AM - 9:30 AM
Room: Stars at Night Ballroom 1
Li et al. First Delivery of the Spot-Scanning Proton Arc Therapy

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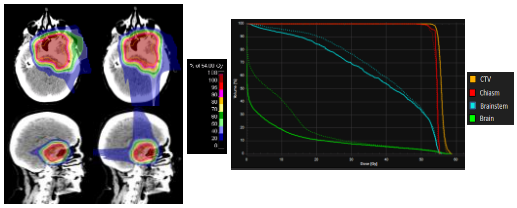
SPArc patient specific plan



SPArc IMPT

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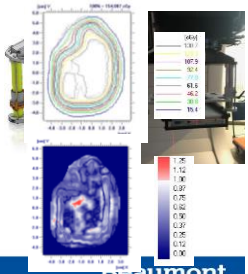
Patient specific SPArc QA

- The brain SPArc plan was delivered in PDAD mode
- The iso-dose was measured using MatrixxOne mounted to the gantry with 2 cm buildup
- The Gamma index (3%/3mm) criteria was used analyze the measurement
- The delivery time is **5 mins** compared to **11 mins** for the IMPT plan.
- The Gamma index reached 98.6%



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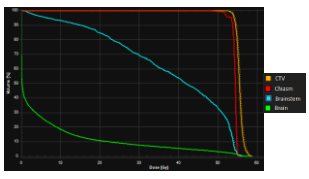
Delivered dose reconstruction

- The actual spot delivered angle position, MUs were imported back to TPS to calculate the delivered dose
- The maximum dose difference in the target is 0.2%
- The Gamma index (1mm/1%) reached 98.3%



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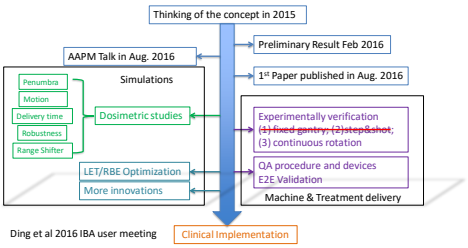

Conclusions

- SPArc addressed three main challenges in the proton beam therapy
  - Plan Robustness
  - Treatment Delivery efficiency
  - Dosimetric Conformity
- The SPArc could release power of PBS optimization via more degrees of freedom
- The SPArc delivery is ***compatible*** with the existing ***clinical proton system***
- Expand the proton beam therapy application to more disease sites or indications.
- Potentially reduce acute toxicity of organs abutting the target
- Increase the proton facility daily treatment throughput

Acknowledgement

- Physics team:
  - Xiaoqiang Li, Ph.D. (co-Inventor): Technique Lead
  - Di Yan D.Sc. (co-Inventor)
  - Jun Zhou, Ph.D. (Joined Emory PTC last year)
  - Gang Liu, Ph.D. Received Young Investigator award in PTCOG 2019
  - An Qin, Ph.D.
- Physician team:
  - Craig Stevens MD., Ph.D.;
  - Peyman Kabolizadeh MD., Ph.D.: Clinical Lead
- IBA team:
  - Guillaume Janssens; Antoine Pouppez; Damien Prieels, Gregory Saive and many more from R&D department
- UCL Miropt
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