Trajectory Modulated Arc Therapy: Application to Partial Breast Irradiation

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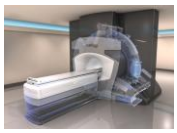
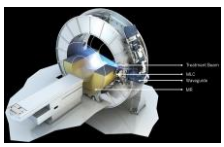
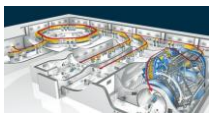
Research and development to advance radiotherapy



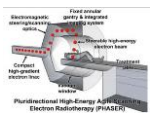


New imaging platforms: MR-hybrids, O-rings, etc. to *improve adaptation and motion management*

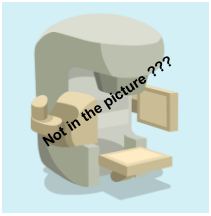
Research and development to advance radiotherapy



New delivery platforms: particles, high-energy electrons, and gamma rays (with special geometry) to *improve dose distributions*



Research and development to advance radiotherapy



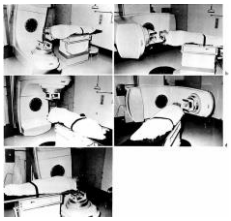
Have we exhausted the delivery options for dose improvements?

Research opportunity:

⇒ dynamic delivery on optimized but arbitrary in shape non-isocentric collision-free trajectories via synchronized motion of ***all*** accelerator axes (*including couch*)

Trajectory Modulated Arc Therapy (TMAT)
4pi
Dynamic Trajectory Therapy

Back to the future



Past:

Proceedings of the Meeting of the American Society for Stereotactic and Functional Neurosurgery, Montreal 1987
Appl. Neurophysiol. 50: 263–268 (1987)

Physical Aspects of Dynamic Stereotactic Radiosurgery

Ervin B. Podgorsak[a], André Olivier[b], Marina Pla[a], Joseph Hazel[b], Alain de Lotbinière[b], Bruce Pike[b]

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Future

- Extracranial trajectories
- individually optimized for each patient
- non-isocentric
- intensity-modulated

Controversy => research opportunity

POINT/COUNTERPOINT

Suggestions for topics suitable for these Point/Counterpoint debates should be addressed to Colin G. Orton, Professor Emeritus, Wayne State University, Detroit: ortonc@comcast.net. Persons participating in Point/Counterpoint discussions are selected for their knowledge and communicative skill. Their positions for or against a proposition may or may not reflect their personal opinions or the positions of their employers.

Noncoplanar beams improve dosimetry quality for extracranial intensity modulated radiotherapy and should be used more extensively

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Colin G. Orton, Ph.D., Moderator

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Motivation: room for improvement


CLINICAL INVESTIGATION Breast

UNACCEPTABLE COSMESIS IN A PROTOCOL INVESTIGATING INTENSITY-MODULATED RADIOTHERAPY WITH ACTIVE BREATHING CONTROL FOR ACCELERATED PARTIAL-BREAST IRRADIATION

Reshma Jagsi, M.D., D.Phil.,* Moran A. Ben-David, M.D.,* Jean M. Moran, Ph.D.,* Robin B. Marsh, C.M.D.,* Kent A. Griffith, M.P.H., M.S.,† James A. Hayman, M.D., M.B.A.,* and Lori J. Pierce, M.D.*

JOURNAL OF CLINICAL ONCOLOGY ORIGINAL

Clinical Investigation: Breast Cancer

Decline of Cosmetic Outcomes following Accelerated Partial Breast Irradiation Using Intensity Modulated Radiation Therapy: Results of a Single-Institution Prospective Clinical Trial

Adam L. Liss, MD,* Marco A. Ben-David, MD,* Reshma Jagsi, MD, DPhil,* James A. Hayman, MD, MBA,* Kent A. Griffith, MPH, MS,† Jean M. Moran, PhD,* Robin B. Marsh, CMD,* and Lori J. Pierce, MD*

Clinical Investigation: Breast Cancer

The Effect of Dose-Volume Parameters and Interfraction Interval on Cosmetic Outcome and Toxicity After 3-Dimensional Conformal Accelerated Partial Breast Irradiation

Interim Cosmetic and Toxicity Results From RAPID: A Randomized Trial of Accelerated Partial Breast Irradiation Using Three-Dimensional Conformal External Beam Radiation Therapy

Dose-volume correlates:
V100, V50, V20?, V5??

Potential solution: many convergent horizontal beams

- Dynamic 'horizontal arcs'
- Combined with prone breast setup to eliminate dose to lung, heart, etc.

Research opportunity: trajectory design

"beam angle optimization radiation therapy" ***135*** *AND "collision"* ***2***

"isocentric technique" ***194*** *VERSUS "nonisocentric technique"* ***6***

- **Develop and incorporate collision detection models in planning, optimization, and delivery**

  Yu VY, Tran A, Nguyen D, Cao M, Ruan D, Low DA, Sheng K. The development and verification of a highly accurate collision prediction model for automated noncoplanar plan delivery. Med Phys. 2015 Nov;42(11):6457-67.

- **Research into beam arrangement optimization without iso-centricity constraints**

Research opportunity: trajectory optimization

Papp D, Bortfeld T, Unkelbach J. A modular approach to intensity-modulated arc therapy optimization with noncoplanar trajectories. Phys Med Biol. 2015 Jul 7;60(13):5179-98.

MacDonald RL, Thomas CG. Dynamic trajectory-based couch motion for improvement of radiation therapy trajectories in cranial SRT. Med Phys. 2015 May;42(5):2317-25.

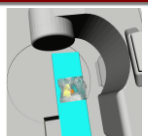
Smyth G, Bamber JC, Evans PM, Bedford JL. Trajectory optimization for dynamic couch rotation during volumetric modulated arc radiotherapy. Phys Med Biol. 2013 Nov 21;58(22):8163-77.

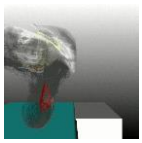
Dong P, Lee P, Ruan D, Long T, Romeijn E, Yang Y, Low D, Kupelian P, Sheng K. 4pi non-coplanar liver SBRT: a novel delivery technique. Int J Radiat Oncol Biol Phys. 2013 Apr 1;85(5):1360-6.

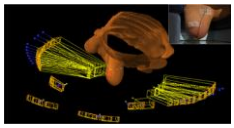
Yang Y, Zhang P, Happersett L, Xiong J, Yang J, Chan M, Beal K, Mageras G, Hunt M. Choreographing couch and collimator in volumetric modulated arc therapy. Int J Radiat Oncol Biol Phys. 2011 Jul 15;80(4):1238-47.

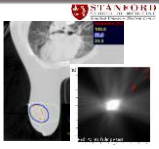
Incorporation of robust collision avoidance and non-isocenricity mandatory for approaches that optimize all degrees of freedom at once.

Research opportunity: sequential trajectory design







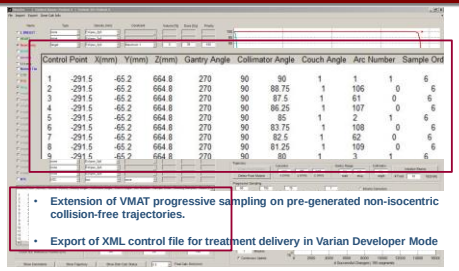


Pros: implementable today via multi beam-IMRT

Cons: potentially suboptimal, takes longer to deliver, start-and-stop couch motion.

Trajectory Modulated Prone Breast Irradiation: A Linac-Based Technique Combining Intensity Modulated Delivery with Motion of the Couch, Benjamin P. Fahriman, Victoria Yu, Kathleen Horst, Lei Xing, and Dimitre Hristov, Radiother Oncol. 2013 Dec;109(3):475-81.

Research opportunity: TMAT optimization

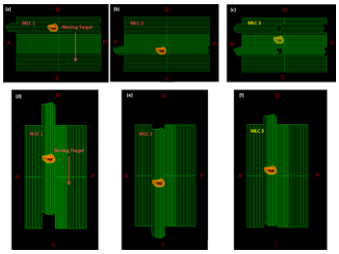


Control Point	X(mm)	Y(mm)	Z(mm)	Gantry Angle	Collimator Angle	Couch Angle	Arc Number	Sample Ord
1	-291.5	-65.2	664.8	270	90	90	1	1	1	6
2	-291.5	-65.2	664.8	270	90	88.75	1	106	0	6
3	-291.5	-65.2	664.8	270	90	87.5	1	61	0	6
4	-291.5	-65.2	664.8	270	90	86.25	1	107	0	6
5	-291.5	-65.2	664.8	270	90	85	1	2	1	6
6	-291.5	-65.2	664.8	270	90	83.75	1	108	0	6
7	-291.5	-65.2	664.8	270	90	82.5	1	62	0	6
8	-291.5	-65.2	664.8	270	90	81.25	1	109	0	6
9	-291.5	-65.2	664.8	270	90	80	1	3	1	6

- **Extension of VMAT progressive sampling on pre-generated non-isocentric collision-free trajectories.**
- **Export of XML control file for treatment delivery in Varian Developer Mode**

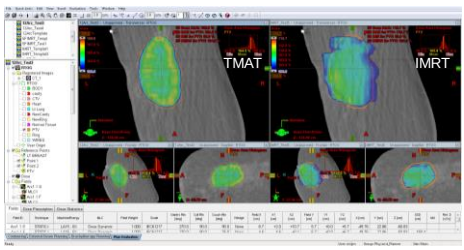
Liang J, Alwood T, von Eyben R, Fahriman B, Chin E, Horst K, Otto K, Hristov D. **Trajectory Modulated Arc Therapy: A Fully Dynamic Delivery With Synchronized Couch and Gantry Motion Significantly Improves Dosimetric Indices Correlated With Poor Cosmesis in Accelerated Partial Breast Irradiation**. Int J Radiat Oncol Biol Phys. 2015 Aug 1;92(5):1148-56.

Challenges with VMAT extension to TMAT optimization



Standard MLC leaf position interpolation used with VMAT progressive sampling is ***not*** directly applicable to TMAT optimization for arbitrary collimator angles

Patient 3: $V_{100\%}$



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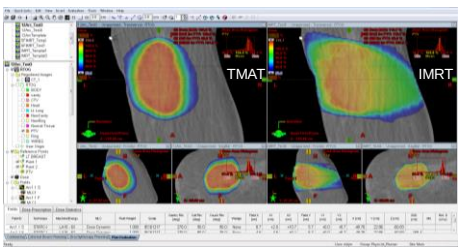
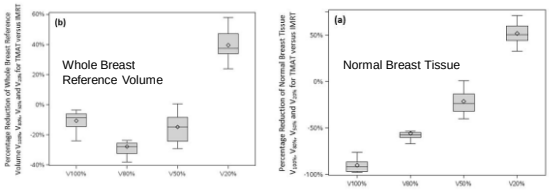
Patient 3: $V_{50\%}$



Liang J, Atwood T, von Eyben R, Fahimian B, Chin E, Horst K, Otto K, Hristov D. **Trajectory Modulated Arc Therapy: A Fully Dynamic Delivery With Synchronized Couch and Gantry Motion Significantly Improves Dosimetric Indices Correlated With Poor Cosmesis in Accelerated Partial Breast Irradiation**. Int J Radiat Oncol Biol Phys. 2015 Aug 1;92(5):1148-56.

Impact

Relative reduction in Whole Breast Reference Volume and Normal Breast Tissue (TMAT versus IMRT) at different dose levels



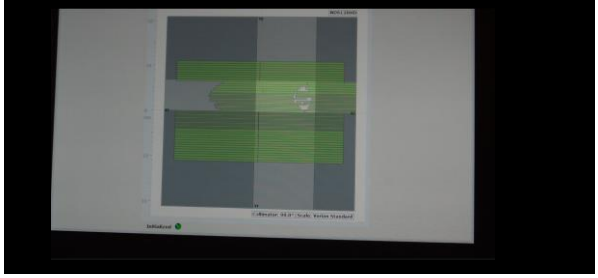
Research interfaces to deliver dynamic trajectories

Liang J, Alasti T, von Eyben R, Fahimian B, Chin E, Horst K, Otto K, Hristov D. **Trajectory Modulated Arc Therapy: A Fully Dynamic Delivery With Synchronized Couch and Gantry Motion Significantly Improves Dosimetric Indices Correlated With Poor Cosmesis in Accelerated Partial Breast Irradiation**. Int J Radiat Oncol Biol Phys. 2015 Aug 1;92(5):1148-56.

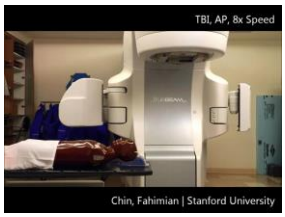
17

TMAT delivery example

TMAT delivery example



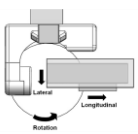
TMAT: TBI Delivery

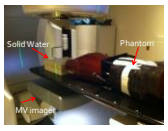


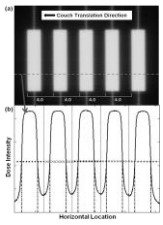
1) Inversely planned with MLCs:
   - Differential sparing of organs
2) Accurate dosimetry
3) Most importantly: Patient comfort
4) No significant additional requirements on room/equipment

AAPM 2015 FEATURED PRESENTATION and BEST IN PHYSICS (THERAPY): Trajectory Modulated Arc Therapy: Development of Novel Arc Delivery Techniques Integrating Dynamic Table Motion for Extended Volume Treatments
E Chin[1*], K Otto[2], R Hoppe[1], L Million[1], B Luo[1], A Koong[1], L Xing[1], A Hsu[1], B Fahimian[1], (1) Stanford University, Stanford, CA, (2) University of British Columbia, Vancouver, BC

Research opportunity: TMAT Quality Control







Yu VY, Fahimian BP, Xing L, Hristov DH. **Quality control procedures for dynamic treatment delivery techniques involving couch motion.** Med Phys. 2014 Aug;41(8):081712. doi: 10.1118/1.4886757. PubMed PMID: 25086522.

Needed: Tools, tests, analysis techniques to evaluate the spatial and temporal fidelity of dynamic concerted motions of all axes

Research opportunity: TMAT grand challenge

Intra-fractional imaging: imaging device attached to table, table position monitoring

Conclusions

- Dynamic delivery on *arbitrary in shape non-isocentric collision-free trajectories* via synchronized motion of *all* accelerator axes (*including couch*) is *largely unexplored*
- Research opportunities exist along all steps of involved with the potential clinical implementation of such techniques: planning, QA delivery/validation, collision detection, and image guidance.
- *Intra-fractional imaging is a key challenge* to implementation.