Emerging Linac based SRS/SBRT Technologies with Modulated Arc Delivery

Lei Ren, Ph.D.
Duke University Medical Center

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Introduction: Treatment delivery techniques

- Static beam treatment:
  - 3D conformal radiation therapy (3D-CRT): forward planning
  - IMRT: inverse planning
- Arc treatment:
  - Dynamic conformal arc therapy (DCAT): forward planning
  - Modulated arc therapy (MAT): inverse planning

Introduction: Multiple target treatments

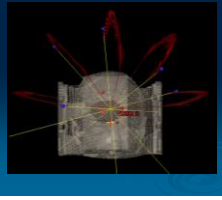
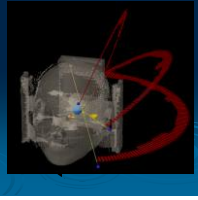
- SRS to complement or replace whole brain radiotherapy (WBRT):
  - Significantly greater stability of function at 6 month.
  - Local control rate at 1yr improved from 71% to 82% (Andrews et al, Lancet, 2004)
- Conventionally multiple plans with different isos to treat targets separately: long setup and delivery time
- Single iso MAT to treat all targets in one plan: faster (less intrafraction motion) and lower MU

Outline

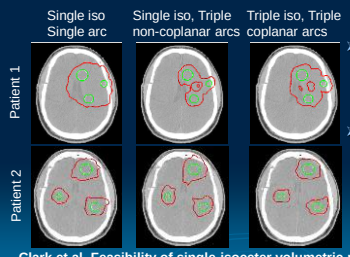
- **Planning process of MAT**
- **Comparison of plan quality and efficiency for single iso MAT vs multi-iso 3D-CRT/DCAT**
- **Quality assurance process**
- **Patient setup and imaging procedures**
- **Summary**

Planning process of MAT: beam setup

- Iso center placed around center of mass of all targets
- 2-5 Non-coplanar arcs (better conformity than co-planar arcs)
- HD MLC (central 2.5mm, outside 5mm) for small tumors

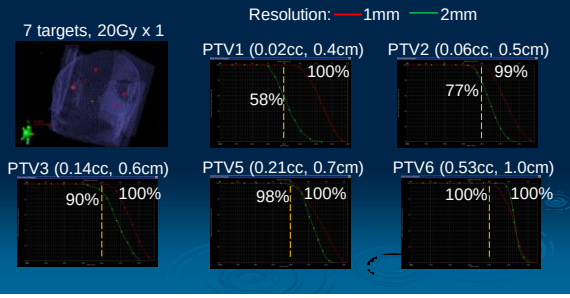
Importance of arc number and orientation in MAT



- Single iso triple non-coplanar arcs has the best dose conformity to PTV.
- Multiple arc plans showed smaller 12Gy (Rx=20Gy) isodose volumes when targets are spaced closely together

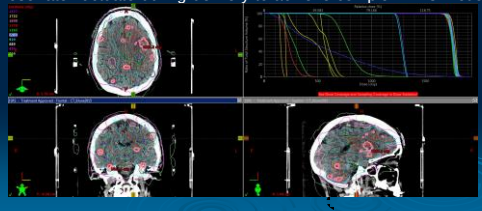
Clark et al, Feasibility of single-isoceter volumetric modulated arc radiosurgery for treatment of multiple brain metastases, IJROBP (2010)

Effects of dose calculation resolution



Single iso MAT plan

36 targets, 8.2Gy x 2 to 34 targets, 6Gy x 2 to 2 targets
Single iso 5 arc VMAT.
Dose rate fluctuate during delivery to achieve complex MLC motion



Plan evaluation

- Conformity index (CI): $CI_{ICRU} = \frac{V_{Rx}}{V_{PTV}}$
  - doesn't guarantee PTV coverage

CI = 1

  - sensitive to the PTV volume size: higher CI for small volumes
- Target coverage: %vol. of target covered by Rx
- Quality of coverage: $\frac{D_{min}\ in\ PTV}{Rx}$

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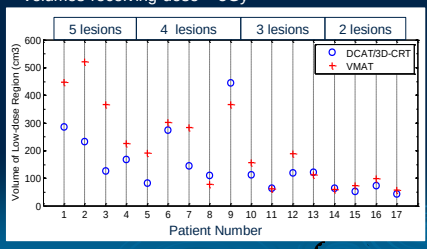
Comparison of single iso MAT vs multi-iso 3D-CRT/DCAT

	DCAT/3D-CRT	VMAT	p value
5 lesions			
Conformity Index	1.46 ± 0.21	1.38 ± 0.19	0.19
Target Coverage (%)	99.44 ± 0.66	99.67 ± 0.29	0.24
Quality of Coverage	0.96 ± 0.02	0.97 ± 0.02	**0.04**
4 lesions			
Conformity Index	1.66 ± 0.44	1.43 ± 0.3	**0.01**
Target Coverage (%)	99.54 ± 0.5	99.63 ± 0.47	0.55
Quality of Coverage	0.93 ± 0.06	0.97 ± 0.02	**0.02**
3 lesions			
Conformity Index	1.75 ± 0.28	1.49 ± 0.36	**0.04**
Target Coverage (%)	99.87 ± 0.14	99.85 ± 0.2	0.73
Quality of Coverage	0.97 ± 0.02	0.99 ± 0.04	**0.04**
2 lesions			
Conformity Index	1.75 ± 0.31	1.32 ± 0.2	**0.0007**
Target Coverage (%)	99.75 ± 0.19	99.85 ± 0.14	0.34
Quality of Coverage	0.96 ± 0.01	0.98 ± 0.02	**0.0008**

Courtesy of Zhiheng Wang and Chi Huang

Comparison of single iso MAT vs multi-iso 3D-CRT/DCAT

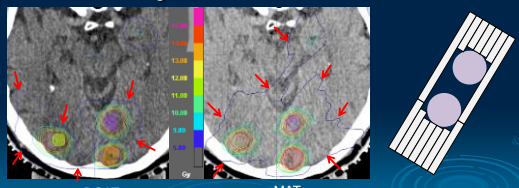
Volumes receiving dose > 5Gy



Courtesy of Zhiheng Wang and Chi Huang

Comparison of single iso MAT vs multi-iso 3D-CRT/DCAT

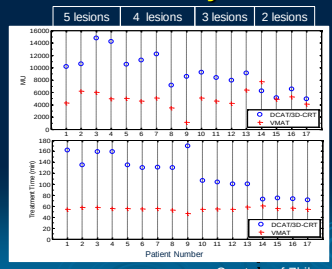
- Larger low dose volume for MAT
  - less flexibility in MLC opening when covering multiple lesions
  - More MLC leakage



DCAT MAT

Courtesy of Zhiheng Wang and Chi Huang

Treatment delivery efficiency



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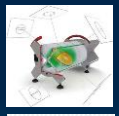
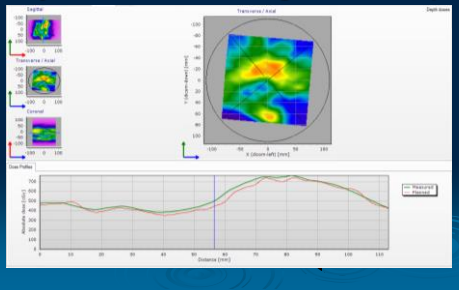
Quality assurance for single iso MAT plans

- Second calc software
- Physics QA measurements:
  - Delta4 (Scandidos)

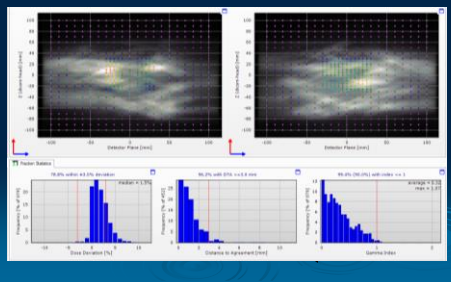


  - Arc check (Sun nuclear)

Quality assurance for single iso MAT plans



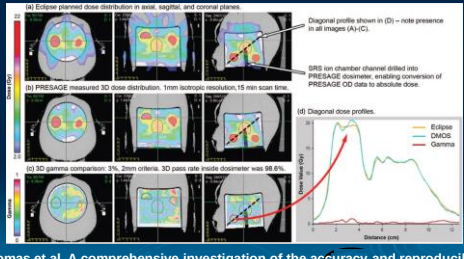
Quality assurance for single iso MAT plans



Quality assurance for single iso MAT plans

- Delta4 and Arccheck:
  - 2D measurement to interpolate 3D dose
  - Limited measurement resolution (5mm-1cm)
- 3D Gel dosimetry:
  - 3D dose measurement
  - 1mm isotropic resolution
  - Inconvenience
  - time sensitive

Quality assurance for single iso MAT plans



Thomas et al, A comprehensive investigation of the accuracy and reproducibility of a multitarget single isocenter VMAT radiosurgery technique, Med. Phys. 2013

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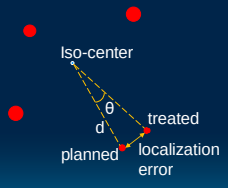
Patient setup and imaging

- **Frame based or frameless masks for brain**
- **Vacuum bag or alpha cradle for body**
- **Imaging** tools:
  - 2D orthogonal kV-kV using on-board imager
  - ExacTrac
  - CBCT

Effects of rotations on localization accuracy of single iso MAT to multi-targets

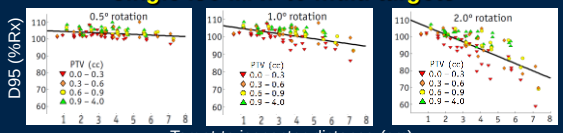


Localization error = 2d*sin(θ/2)

Localization error	θ = 0.5°	θ = 1°	θ = 2°
d = 1cm	0.1mm	0.2mm	0.3mm
d = 3cm	0.3mm	0.5mm	1mm
d = 5cm	0.4mm	0.9mm	1.7mm
d = 7cm	0.6mm	1.2mm	2.4mm

Minimize iso-to-target distance during planning and rotational errors during set up

Effects of rotations on localization accuracy of single iso MAT to multi-targets



- D95 decreased with increasing rotation angle
- D95 decreased with increasing target-to-iso distance
- D95 decreased with decreasing target volume

Roper et al, Single-isocenter Multiple-Target Stereotactic Radiosurgery: Risk of Compromised Coverage, IJROBP (2015)

Challenges with single-iso MAT to multi-targets in SBRT

- Non-rigid.
- Respiratory motion
- Relative distance and orientation between targets can change, may not be correctable by rigid shifts and rotations of the patient

Challenges with single-iso MAT to multi-targets in SBRT

Breath-hold lung SBRT. 5Gy x 10 to both targets

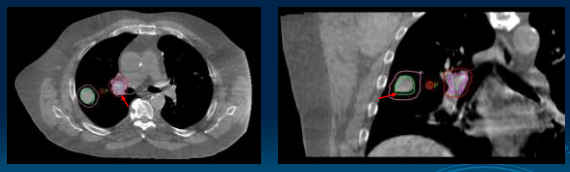
CBCT after shifts

CBCT after shifts and 16deg rotation

- Relative rotation too large to correct

Challenges with single-iso MAT to multi-targets in SBRT

Breath-hold lung SBRT. 7.5Gy x 8 to both targets



- **Targets not fully within GTV, but within PTV after CBCT correction**

Challenges with single-iso MAT to multi-targets in SBRT

- Limit to targets within close distance
- Minimize respiratory motion of targets: targets in the upper lobe of lung, consider breath hold
- Larger margin to account for set up uncertainties
- Correct rotational errors during set up if possible

Summary

- **Single iso MAT generates comparable or superior dosimetric distribution to the targets with substantially reduced MU and treatment time, compared to multi-iso 3D-CRT or DCAT plans**
- **QA needs to be carefully developed to verify the 3D dose delivered from complex MLC motion in MAT**
- **Correcting rotational errors is critical for patient set up in single iso MAT**
- **Cautions need to be taken for single-iso MAT to multi-targets in SBRT to account for errors in target alignment**