Post Treatment Log File Based QA Varian

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Learning Objectives

- What information could be accessed via log files
- Scenarios where Log files could be used.
- How log files could be used for error catching in patient safety
- Limitations of log files

What log files can give…

Could be directly compared with plan parameters fraction by fraction

- By passing the R&V system to detect any transfer errors
- Control point based machine delivery accuracy
- Integrity check of plan in R&V system
- Site specific imaging shift accuracy
- Verify patient name, ID, and plan name
- Calculate delivered 4D dose and DVH
- Error catching or beam off flag

TrueBeam Trajectory log files

2 Format

This section describes the trajectory log file format. The trajectory log file is divided into three sections:

1. Header
2. Subbeams
3. Axis data

The header has a fixed length of 1024 bytes. Not all of the 1024 bytes in the header are used. Unused bytes at the end of the header may be used for future expansion to the trajectory log file.

Integers and floats are stored in little endian (Intel) format.

The system can record data from a 10-minute treatment.

For a 250 axis machine (200 leaves plus other motion axis) there are 500 values per sample, and each value is 4 bytes. Sampling at 100 Hz (every 10 ms) generates 200 KB of data per second, or 12 MB per minute. The trajectory log for a 10 minute treatment contains 120 MB of data.

2.1 Header

The following table describes the header format.

Data Description	Size	Type
Signature 'VOSTL'	16 bytes	Zero terminated Unicode string
Version '1.1'	16 bytes	x.y formatted as a zero terminated Unicode string.
Header Size (fixed for now at 1024)	4 bytes	Integer
Sampling Interval in milliseconds The sampling interval must be an integral multiple of the system heartbeat of 10ms.	4 bytes	integer
Number of axes sampled, includes MU and gating if applicable. Indicates the length of the next field. Axis enumeration.	4 bytes	integer
Axis enumeration (The MLC is enumerated as a single axis. If included, all leaves are included.) Coll Rtn – 0 Gantry Rtn – 1 Y1 – 2 Y2 – 3 X1 – 4 X2 – 5 Couch Vrt – 6 Couch Lng – 7	Number of axes * 4 bytes	Integer array

Trajectory Log File Structure

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Couch Lat – 8 Couch Rtn – 9 MU – 40 Beam Hold – 41 Control Point - 42 MLC - 50		
Samples per axis This is one for most axes. For the MLC, it is the number of leaves and carriages.	Number of axes * 4 bytes	Integer array
Axis Scale 1- Machine Scale 2- Modified IEC 61217	4 bytes	Integer enumerator
Number of subbeams.	4 bytes	integer
Is Truncated? The system is configured to record 60000 snapshots (10 minutes with a 10ms sampling interval). If the plan exceeds 10 minutes, then the system stops recording data to the trajectory log and sets this flag to true (1). Otherwise the flag is false (0).	4 bytes	Integer 1=truncated 0=not truncated
Reserved	1024 – (56 + Number of axis * 8)	N.A.
Subbeam 1	80 bytes	Subbeam structure
Subbeam 2	80 bytes	Subbeam structure
	...	
Subbeam n – 1	80 bytes	Subbeam structure
Subbeam n	80 bytes	Subbeam structure
Axis data Snapshot 1	2 * 4 * number of samples	Float array
Axis data Snapshot 2	2 * 4 * number of samples	Float array
...	...	...
Axis data Snapshot N – 1	2 * 4 * number of samples	Float array
Axis data Snapshot N	2 * 4 * number of samples	Float array

Trajectory Log File Structure

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2.2 Subbeam Structure

A subbeam is created when a series of treatment fields are made automatic. Each previously independent field is now handled as a subbeam.

Each subbeam is 80 bytes long and has the following structure:

Data Description	Size	Type
cp Control Point. Internally-defined marker that defines where the plan is currently executing.	4 bytes	integer
mu Dose delivered in units of MU.	4 bytes	float
radTime In units of seconds. Expected (calculated) irradiation time of the subbeam. When the actual irradiation time exceeds the expected radiation time, the system terminates the plan. If the expected irradiation time is zero, then the system does not terminate the plan due to actual irradiation time.	4 bytes	float
Seq Sequence number of the subbeam.	4 bytes	integer
Name Name of the subbeam.	32 bytes	Zero terminated Unicode string
Reserved	32 bytes	Zero terminated Unicode string

2.3 Axis Data Structure

The axis data is stored immediately after the subbeam data. The data is stored as a series of snapshots. Each snapshot is a sequence of arrays in the following order

Values[Axis1], Values[Axis2], ..., Values[AxisN].

Each array contains the number of values needed for that axis. SamplesPerAxis[AxisJ] values. Each value has two fields, expected and actual.

Values are stored in Varian scale.

Here is an example in which MU, Gantry Rotation and the 120-leaf standard definition MLC are sampled. Note that this example excludes the information for the other axes, concentrating on the MU, Gantry rotation, and the MLC.

MU expected	MU actual	Gantry expected	Gantry actual	MLC Carr A expected	MLC Carr A actual	MLC Carr B expected	MLC Carr B actual	MLC Carr A Leaf 1 expected	...	MLC Carr A Leaf 60 actual	MLC Carr B Leaf 1 expected	...	MLC Carr B Leaf 60 actual

Trajectory Log File Structure

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TruBeam records info every 20 ms in binary format

Gantry angle, collimator angle, couch angle, couch translations, jaw settings, MU, MLC leaf positions

The units are: cm for linear axes, degrees for rotational axes, MU for dose

C series dynalog files

When this feature is enabled, as soon as a dynamic MLC treatment finishes, the controller writes those treatment DynaLog files to the DynaLogs folder subdirectory within the default FTP root directory on the MLC workstation. For example:

`\Oncology\MLC\Controller\exec\DynaLogs\`

Unlike manually-generated DynaLog files, the controller assigns unique file names to the automatically generated DynaLog files. The Revision B MLC controller names the files using the following convention:

`CYYYYMMDDHHNNSS_<Patient ID>.dlg`

where the values are as follows:

C	A or B for the MLC carriage (leaf bank)
YYYY	4-digit year
MM	2-digit month
DD	2-digit day of the month
HH	24-hour clock time stamp
NN	minutes time stamp
SS	seconds time stamp
<Patient ID>	The Patient ID

Line	Format	Description
1	B	Letter indicating version
2	<Lastname>,<Firstname>,<ID>	Patient information, up to 25 characters
3	<PlanUID>,<Beam Number> or <Plan filename>	Treat 6.5 or greater or Standalone[a]
4	<long>	Tolerance
5	<long>	Number of leaves in MLC
6	<long>	Clinac Scale 0 = Varian scale 1 = IEC scale (IEC 60601-2-1 only) **Note:** *The IEC 61217 scale is not available for DynaLog files.*

a. The logic for determining the third line is as follows: If the Field Serial number is zero and the PlanUID is non-zero, it is assumed to be Treat 6.5 or greater. If both the Field Serial number and the PlanUID are zero, the filename is used. If the filename is an empty string, a blank line is written.

File Content

Each line of the DynaLog file contains the following:

Column	Format	Description
1	<long>	Current dose fraction or current gantry rotation

Note: *For RapidArc and conformal arc plans, dose fraction information is displayed only if you remove the # character preceding the diagUseRapidArcDynalogFormat command in the MLC controller startup script. In all other cases, gantry rotation in tenths of a degree is displayed if you retain the # character preceding the diagUseRapidArcDynalogFormat command.*

Column	Format	Description
2	<long>	Previous segment number (starting with zero)
3	<long>	Beam hold-off state 2 = LFIMRT carriage group transitions 1 = MLC beam hold-off signal asserted 0 = MLC beam hold-off signal not asserted
4	<long>	Beam on state 1 = Clinac beam is on 0 = beam is off
5	<long>	Previous segment dose index or previous segment gantry angle
6	<long>	Next segment dose index or next segment gantry angle
7	<long>	Gantry rotation in 10th of a degree
8	<long>	Collimator rotation in 10th of a degree
9	<long>	Upper Y1 jaw position in mm in the isoplane
10	<long>	Upper Y2 jaw position in mm in the isoplane
11	<long>	Lower X1 jaw position in mm in the isoplane
12	<long>	Lower X2 jaw position in mm in the isoplane
13	<long>	Carriage expected position in 100th of a mm
14	<long>	Carriage actual position in 100th of a mm
The remaining columns contain the following values for each leaf in the carriage. (nLeaf = 0, 1, 2, and so on)		
4*nLeaf + 15	<long>	Expected position
4*nLeaf + 16	<long>	Actual position
4*nLeaf + 17	<long>	Previous field position
4*nLeaf + 18	<long>	Next field position

Note:

- *All dose fractions range from 0 to 25000.*
- *All gantry and collimator angles are recorded in tenths of degrees, Varian scale.*
- *All jaws are recorded in millimeters in the isoplane.*
- *All carriage and leaf positions are recorded in hundredths of millimeters, in the leaf (physical) plane. Zero is at the centerline. Positive means retracted. Negative means extended across the centerline.*

Varian C series clinac records info every 50 ms in Ascii format

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1. What information is currently unavailable via TrueBeam Trjectory logfiles

3% 1. 1MLC positions, and gantry angles

1% 2. Collimator angles, and x/y jaw positions

86% 3. Output, flatness, and symmetry of the machine

7% 4. 4Couch angle , and couch translations

3% 5. Delivered MU, and dose rate

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- Answer: 3 – output/flatness/symmetry
- References:

- Varian medical system, “TrueBeam trajectory log file specifications”, pages 9-10
- Jianguo Qian, Lei Xing, Wu Liu, Gary Luxton “Dose verification for respiratory-gated volumetric modulated arc therapy.” Phys. Med. Biol. 56:4827-4838 (2011)

Dynalog based Monte Carlo for patient specific QA

TABLE II. RapidArc MLC DynaLog file analysis.

Plan	No. of beam-on set to 0	Leaf position errors (%) <0.05 mm	0.05–0.5 mm	0.5–1 mm	1.0–1.5 mm	1.5–2.5 mm	>2.5 mm
1	8	58.79	22.98	13.36	4.83	0.04	0
2	6	60.90	20.10	13.55	5.43	0.02	0
3	9	63.78	21.29	10.94	3.96	0.03	0
4	8	60.64	23.48	11.66	4.20	0.01	0
5	11	67.89	24.18	5.97	1.95	0	0
6	6	61.84	20.96	12.74	4.44	0.02	0
7	8	59.12	21.43	14.82	4.62	0.01	0
8	9	60.10	22.58	12.77	4.49	0.06	0
9	6	57.55	21.61	15.65	5.18	0.01	0
10	6	58.42	23.43	13.20	4.92	0.03	0

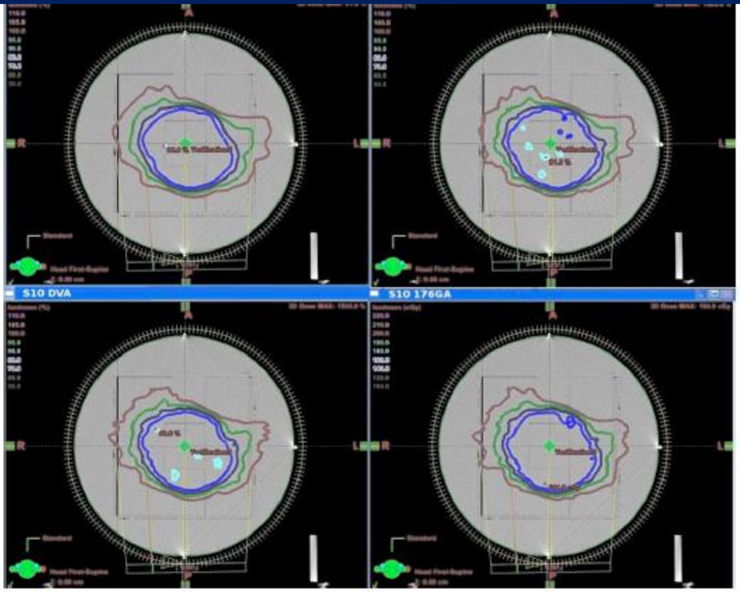
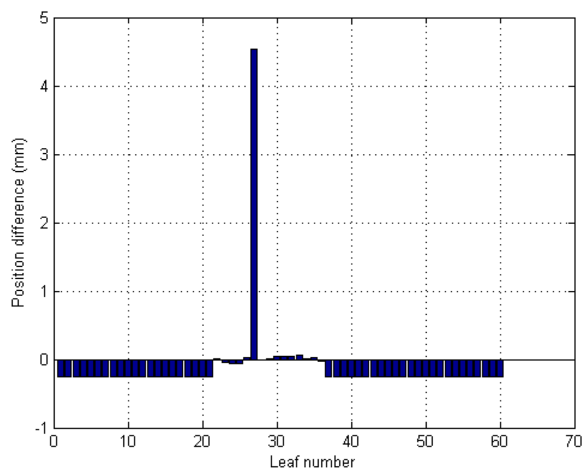


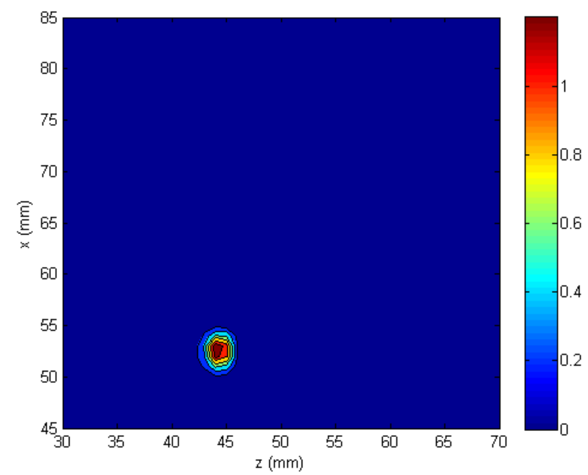
FIG. 5. Dose distribution comparison between RapidArc TPS (top left), S10 Dyna (top right), S10 DVA (bottom left), and 176 GA (bottom right) on a water-equivalent cylinder for plan 4.

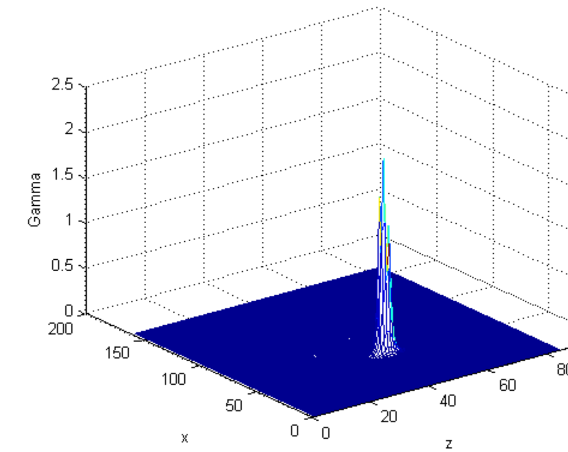
For each plan three Monte Carlo dose calculations were performed; one using continuous gantry rotation with LINAC log files (referred to as S10 Dyna), one using continuous gantry rotation with TPS generated MLC control files (referred to as S10 DVA), and one using 176 fixed gantry angles with TPS MLC control files (referred to as S10 176GA). Comparison between Eclipse TPS and Monte Carlo

Teke *et al.* Med. Phys. 37 (1) 116-123

MLC leaf position difference map between plan and delivery

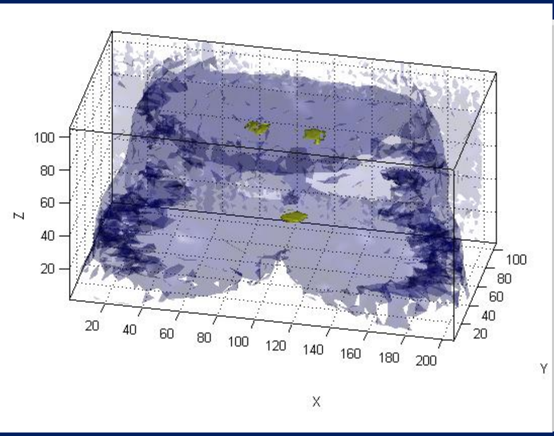


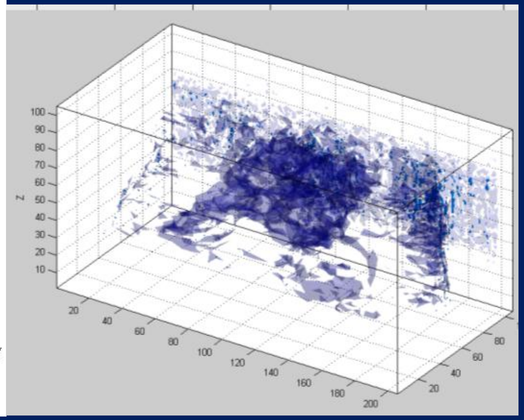


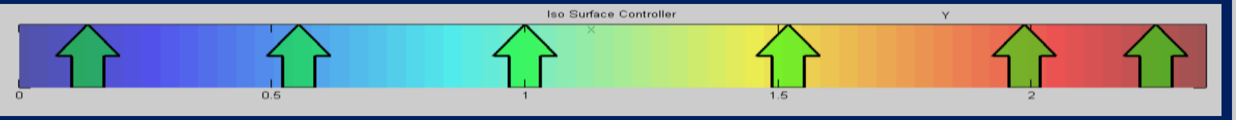


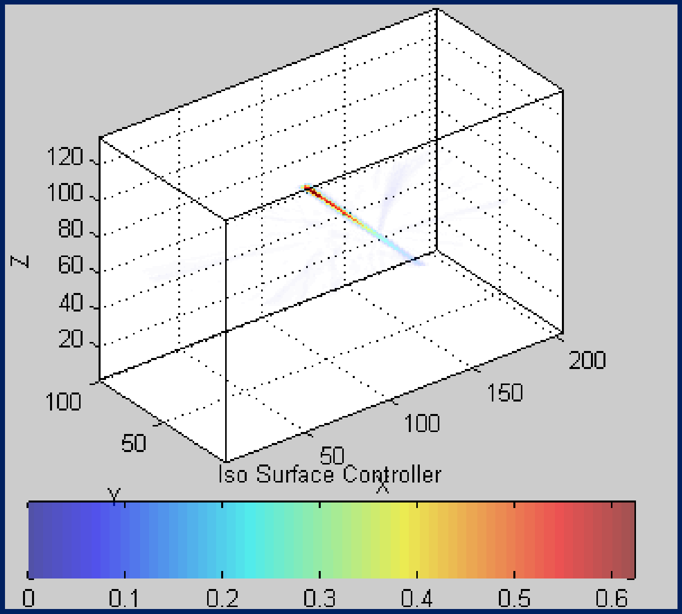
Reconstructed MLC leaf position difference map between plan and delivery, using dynalog files, for a given control point of an IMRT plan. MLC number 27 was intentionally shifted by 4.5 mm from plan to delivery. This signal could be used to flag the clinac beam off, and to warn the therapists.

3D dose difference map for a Pelvic patient









TrueBeam

Trilogy

Color map shows the magnitude of the % dose difference

One MLC moved by 0.5cm, 1.0cm , and 0.5 cm in three consecutive control points in a RapidArc plan. Dose difference of 0.5% could be detetcted

"A technique to detect dosimetric errors as low as 0.5% arising from MLC leaf shifts in RapidArc" **K. Wijesooriya**, J. Nawrocki, P.W.Read, J.M. Larner – Oral presentation at 2013 Annual AAPM meeting in Inidanapolis, IN, *Medical Physics* 40; 2013.

Millenium MLCs

7.0 120 Multileaf Collimator (MLC) Specifications

All scale references below are per IEC 61217

Performance Specifications	Specification
MLC leaf end position accuracy at all leaf positions relative to the collimator axis[1]	±1 mm
MLC leaf end position reproducibility at all leaf positions relative to the collimator axis[1]	±0.5 mm
Descriptive Specifications	
MLC leaf side position accuracy at all leaf positions relative to the collimator axis[1]	±1 mm
MLC leaf side position reproducibility at all leaf positions relative to the collimator axis[1]	±0.5 mm
Number of leaves	120
Central high resolution leaf width (central 20 cm, leaf width projected at isocenter)	5 mm
Outboard leaf width (outer 20 cm, leaf width projected at isocenter)	10 mm

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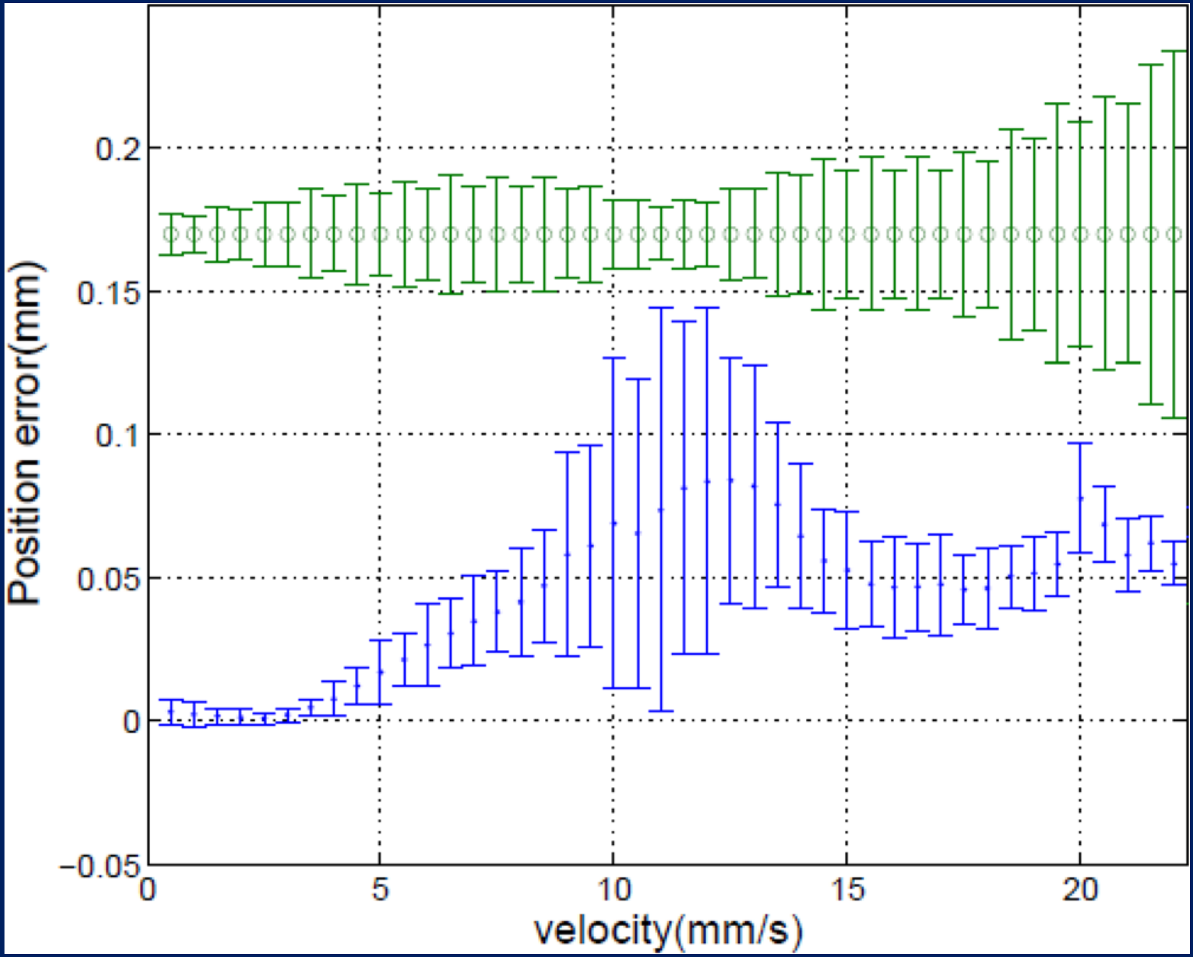
2. What is the Millenuim MLC leaf position accuracy relative to the collimator axis?

1%	1.	5 mm
2%	2.	2 mm
56%	3.	1 mm
40%	4.	0.5 mm
1%	5.	0.6 mm

- Answer: 3 – 1mm
- References:
- Varian Medical system, “TrueBeam system specifications”, page 7

MLC Leaf Error as a Function of Leaf Velocity



MLC leaf position error as a function of leaf velocity for a given for all active leaves are shown here (lower graph with the standard deviation as error bars). Top plot is merely to show the statistical error for each of the points below. As expected since every leaf has to start and end with zero velocity the statistical accuracy is highest for those points.

K. Wijesooriya, et al., “RapidArc patient specific mechanical delivery accuracy under extreme mechanical limits using log files”, Med. Phys.(2012) 39 (4) 1846-1853

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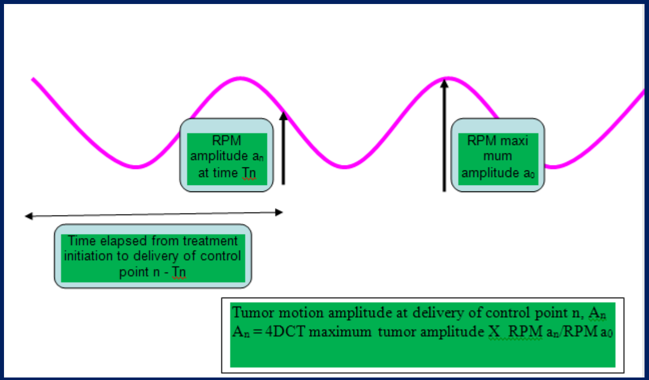
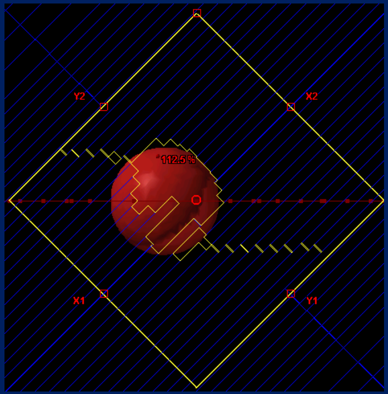
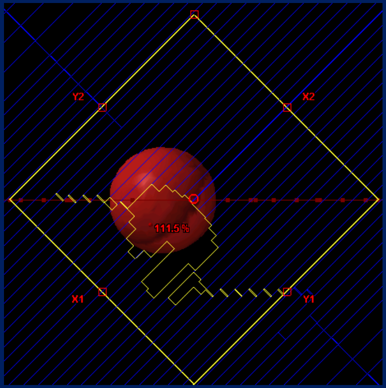
4D delivered dose per fraction

- Use trajectory-log/dynalog files to obtain the delivered treatment times for each control point
- For each control point, log files provide:
  - Time elapsed since the treatment initiation
  - Delivered mechanical parameters including MLC leaf positions for the active leaves
  - Delivered MU
- Tumor motion, as a function of time
  - Patient's RPM signal obtained during the treatment delivery
  - Normalized to the maximum internal tumor motion amplitude from the patient specific 4DCT or daily flouroscopic motion study.
- Coincidence between RPM and beam origination





Original plan



Motion affected plan

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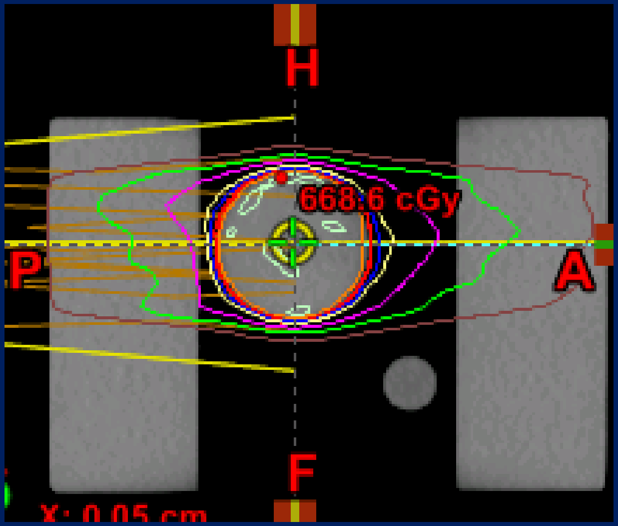
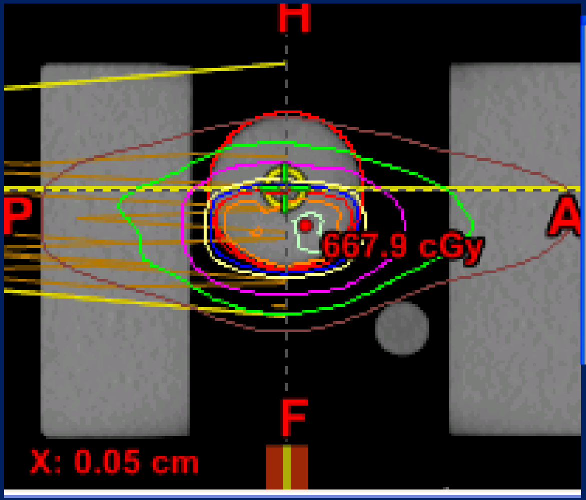
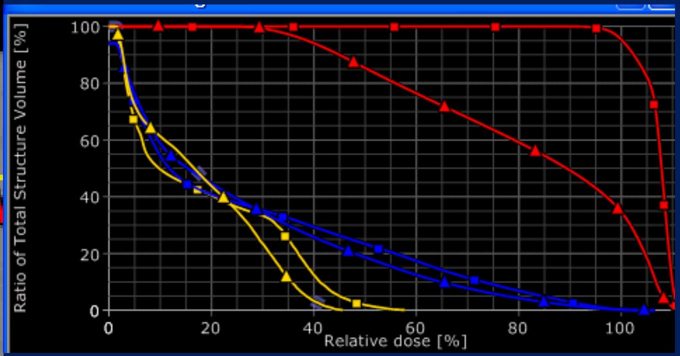
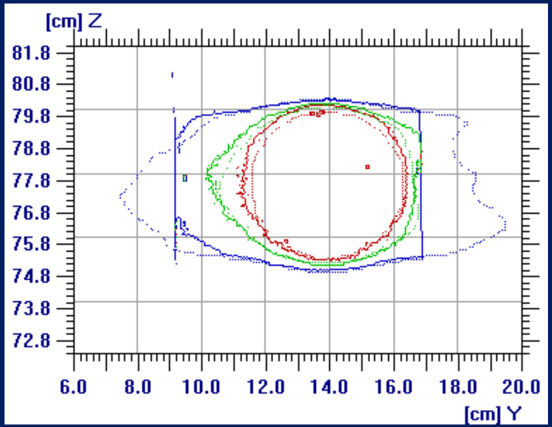
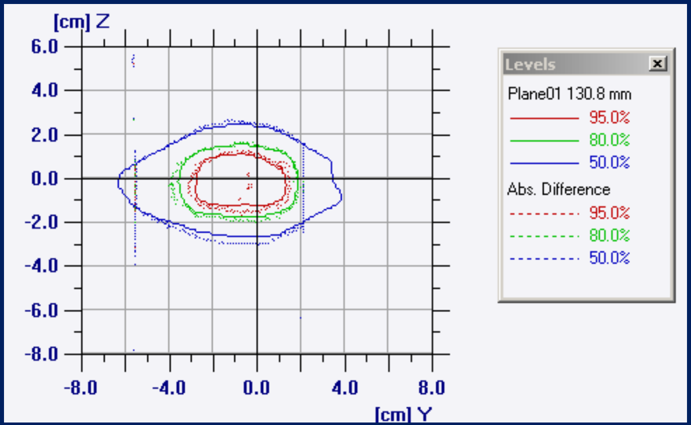






Motion amplitude of 2.5 cm





Comparison: Simulation to Measurement gafchromic film

Original plan

Motion affected plan

"A novel technique to evaluate 4D dose delivery to a moving tumor" K. Wijesooriya, E. Aliotta, P.W.Read, S. Benedict, J.M.Larner, - Oral presentation at 2013 Annual AAPM meeting in Indianapolis, IN, *Medical Physics* 40; 2013

Log files to catch errors at the linac

- D. Rangaraj et al, “Catching errors with patient-specific pretreatment machine log file analysis” Practical Radiation Oncology 2013 (volume 3 issue 2 Pages 80-90
- Krishni Wijesooriya et al. “ Catching errors with trajectory log files” 2015 Annual AAPM meeting, Anaheim, Ca
- Krishni Wijesooriya et al. “ Site specific image guided radiotherapy (IGRT) tolerances for patient safety” 2015 Annual AAPM meeting, Anaheim, Ca

Using log files to monitor Tx

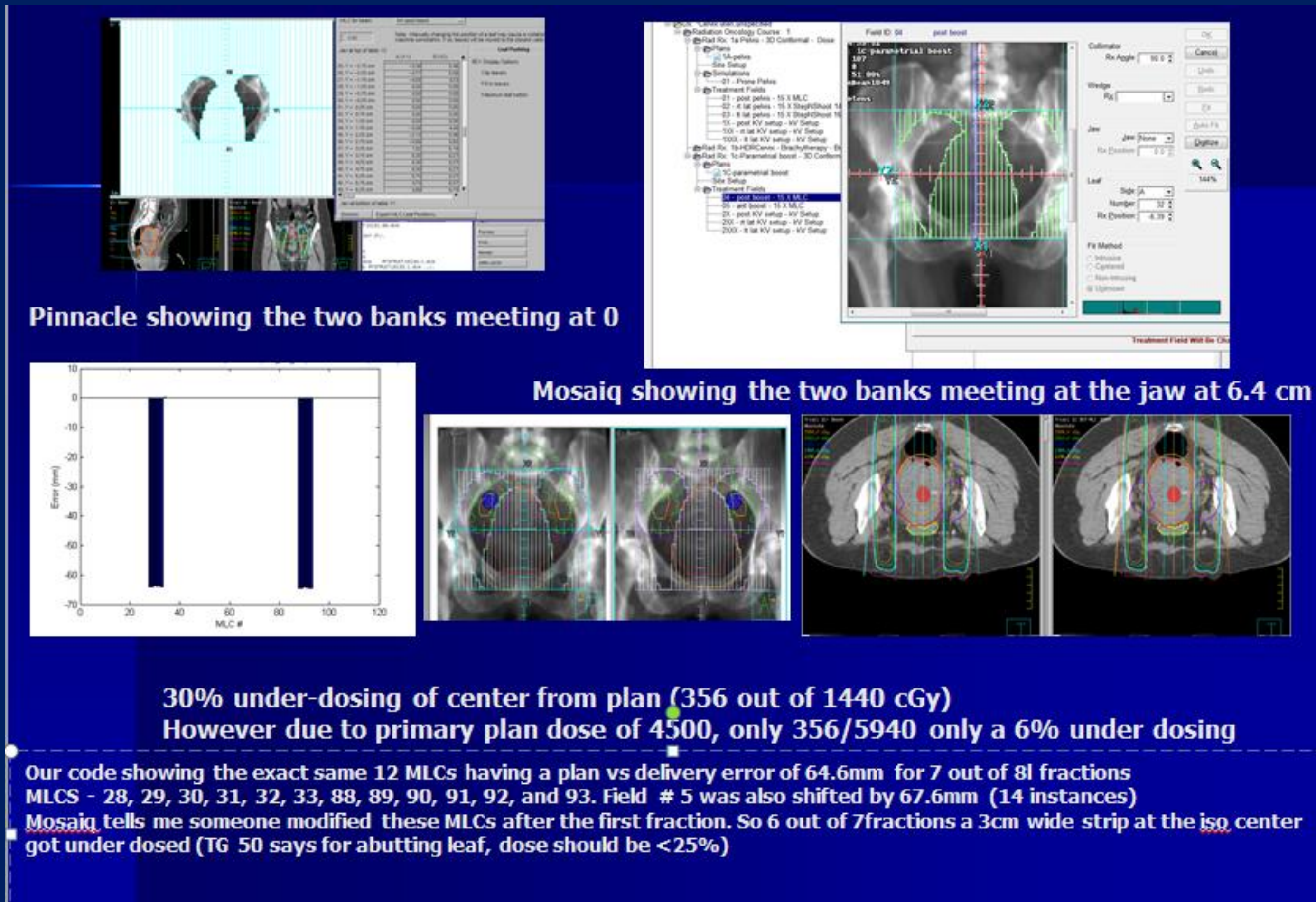
- One year period patient all types of Tx fractions treatd at TrueBeam
- 131 parameters checked at every 20 ms
- 1287 VMAT fields, and 18282 other fields
- 282645 control points (177x1287 +18282 x 3)
- 37 Million parameters (282645 x 131) checked at every 20 ms
- Depending on the time one control point takes to deliver, this can lead to more than 100 Million parameters!

Parameter	# beams/Arcs	Couch angle (deg)	Gantry angle (deg)	Collimator angle(deg)	Jaw position (mm)	MLC leaf position(mm)	Cumulative dose(MU)
IMRT	16888	0.00 ±0.02 -0.10 – 0.10	0.00 ±0.02 -0.08 – 0.10	0.00± 0.00 -0.03 -0.06	0.00 ± 0.00 0.00 – 0.00	0.00 ± 0.02 -0.26 – 0.50	0.00 ± 0.09 -0.99 – 0.42
3D	1225	1.0 ±0.03 -0.1 – 0.1	0.00 ±0.01 -0.07 – 0.09	0.00± 0.00 -0.04 -0.00	0.00 ± 0.00 0.00 – 0.00	0.02 ± 0.01 -0.03 – 0.04	0.00 ± 0.13 -0.99 – 0.99
VMAT	1286	1.0 ±0.07 -0.81 – 0.47	0.09 ±0.15 -0.23 – 0.32	0.00± 0.00 0.00– 0.00	0.00 ± 0.55 -0.99– 0.99	-0.04 ± 0.65 -0.92 – 0.71	0.02 ± 0.28 -0.51 – 0.51
Electron	42	0.01±0.02 -0.05– 0.07	0.00 ±0.02 -0.07 – 0.05	0.00 ±0.00 0.00 0.00	0.00 ± 0.00 0.00 -0.00	NA	0.09 ± 0.21 -0.02 – 0.99

Table I: Systematic (mean) and random (standard deviation) errors of delivery, divided in to treatment modality and treatment site. The mean errors quoted here are the mean values of maximum differences between plan and delivery

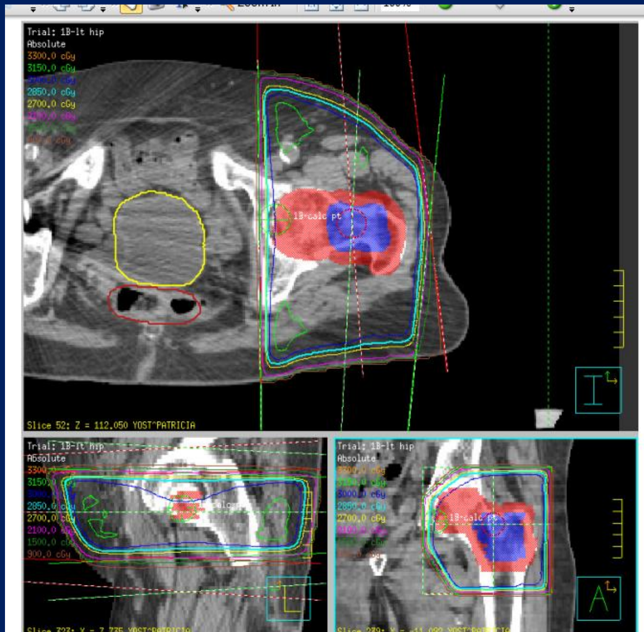
Krishni Wijesooriya et al. " Catching errors with trajectory log files" 2015 Annual AAPM meeting, Anaheim, Ca

Using log files to catch erros: MLCs not according to plan



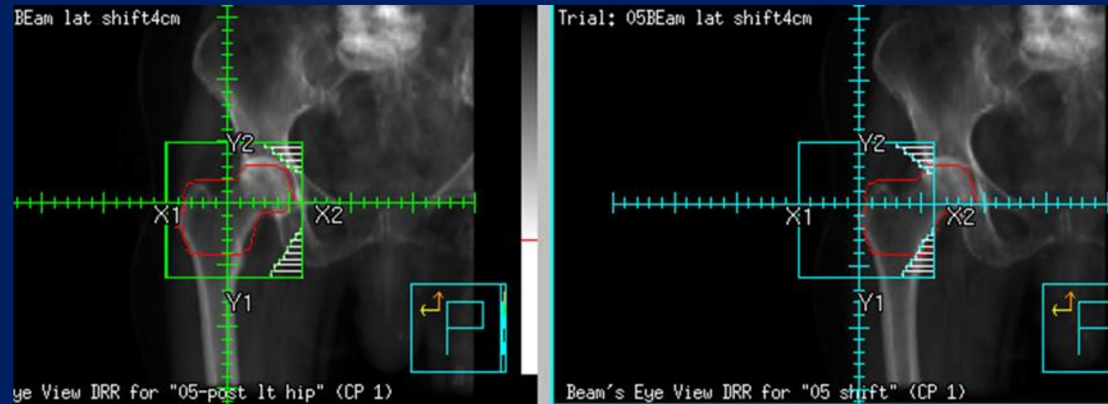
Krishni Wijesooriya et al. “ Catching errors with trajectory log files” 2015 Annual AAPM meeting, Anaheim, Ca

Imaging iso center not followed throughout Tx day

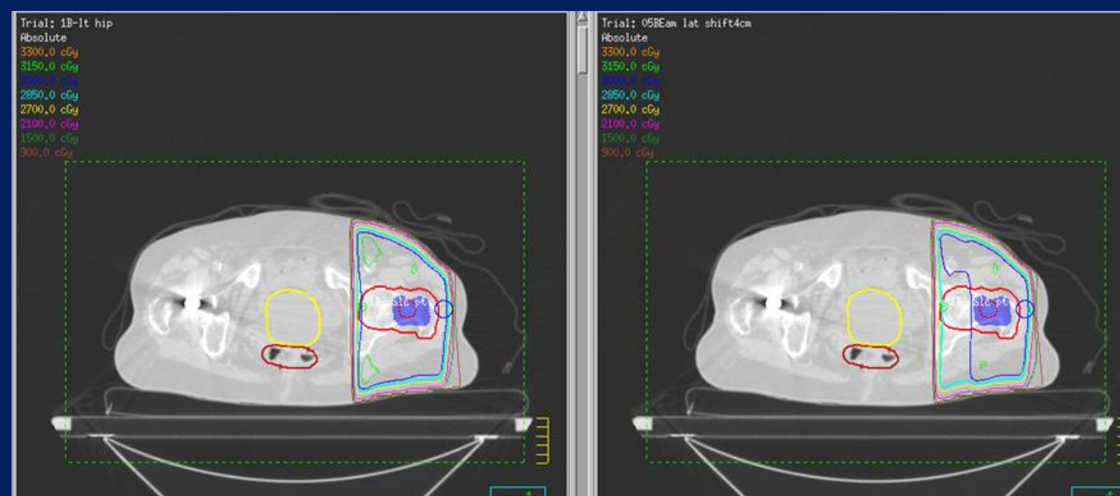


Pinnacle showing the PTV

Our code show the couch was laterally shifted from imaging iso center just for the field 05 by 3.7cm laterally for one day out of 10 fractions. This was confirmed by Mosaiq values.



Beam 05 is at gantry = 183 post. PTV coverage reduced from 98.8% to 74% -total dose



Krishni Wijesooriya et al. " Site specific image guided radiotherapy (IGRT) tolerances for patient safety" 2015 Annual AAPM meeting, Anaheim, Ca

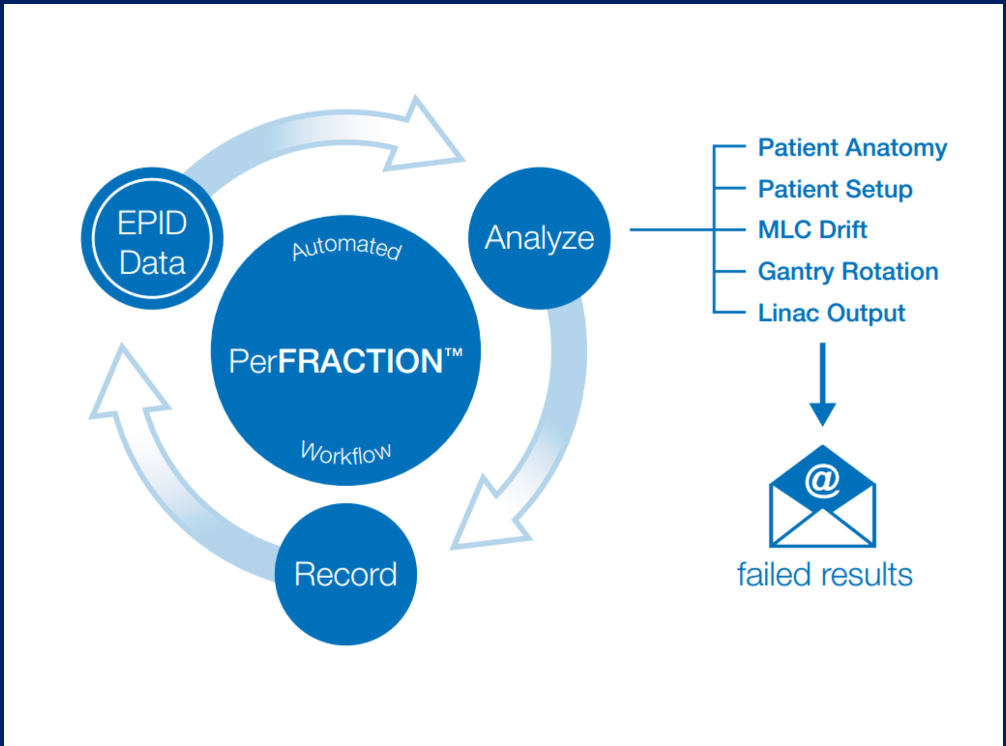
QUASAR ADQ software

- Automated comparison of machine log files to planned treatments
- Administrative reports document patient specific QA every day... automatically
- Compatible with Varian Dynalog and TrueBeam Trajectory log files

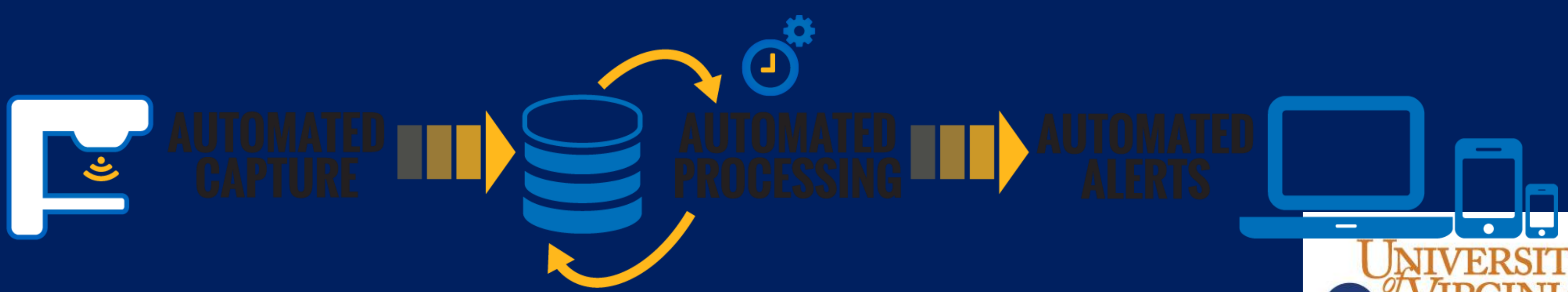
Courtsey of Modus Medical Devices Inc.

The PerFRACTION™ Solution from Sun Nuclear

- <u>Automatic</u> DICOM file capture & analysis
- <u>Automatic</u> Email notification of failures
- <u>Automatic</u> EPID response calibration and modeling
- 3D reconstruction dose using hybrid data from EPID and log file
- For both pretreatment and each fraction



Courtesy of Jie Shi, Sun Nuclear Corporation



Independent verification of Log file based QA

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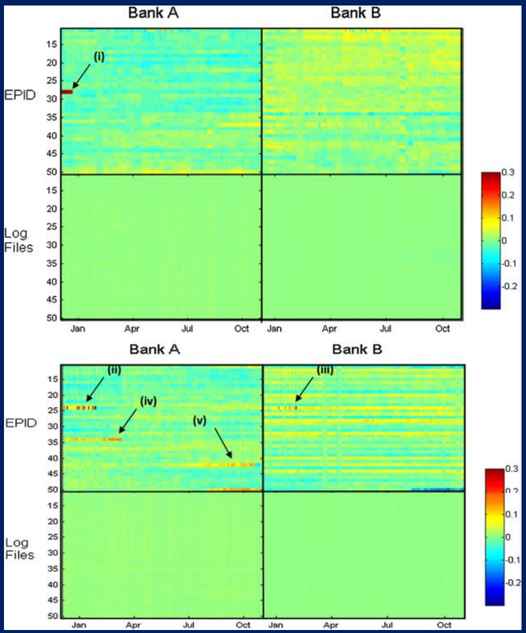
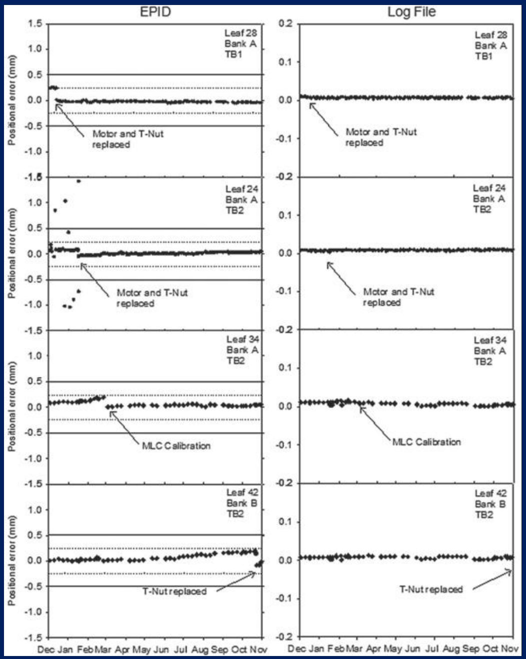
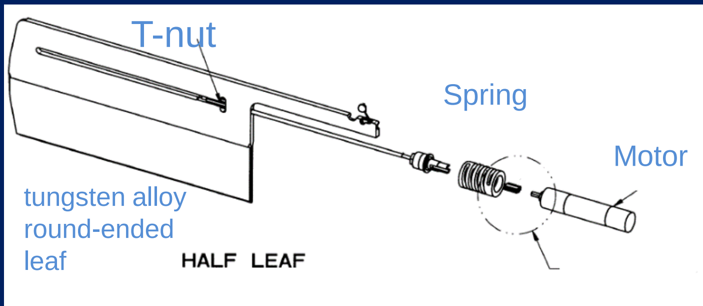
- By inserting deliberate errors and assessing the ability of the method to detect them

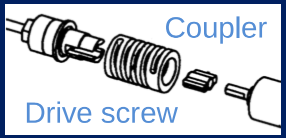
- Portal dosimetry (Stell A M, Li J G, Zeidan O A and Dempsey J F 2004 An extensive log-file analysis of step-and-shoot intensity modulated *Med. Phys.* **31** 1593–602)
- Diode arrays (Li J G, Dempsey J F, Ding L, Liu C and Palta J R 2002 Validation of dynamic MLC-controller log files using a two-dimensional diode array *Med. Phys.* **30** 799–805)

Limitations of Log files









1. Trajectory log files may not detect MLC errors:
   1. Degradation of the motor performance coupled with a loss of counts by the encoder
   2. A faulty or loose t-nut

A. Agnew, et al., “Monitoring daily MLC positional errors using trajectory log files and EPID measurements for IMRT and VMAT deliveries”, Phys. Med. Biol. (2014) 59 N49-N63

2. Ignores the patient – cannot detect patient changes/ setup by a log file solution alone

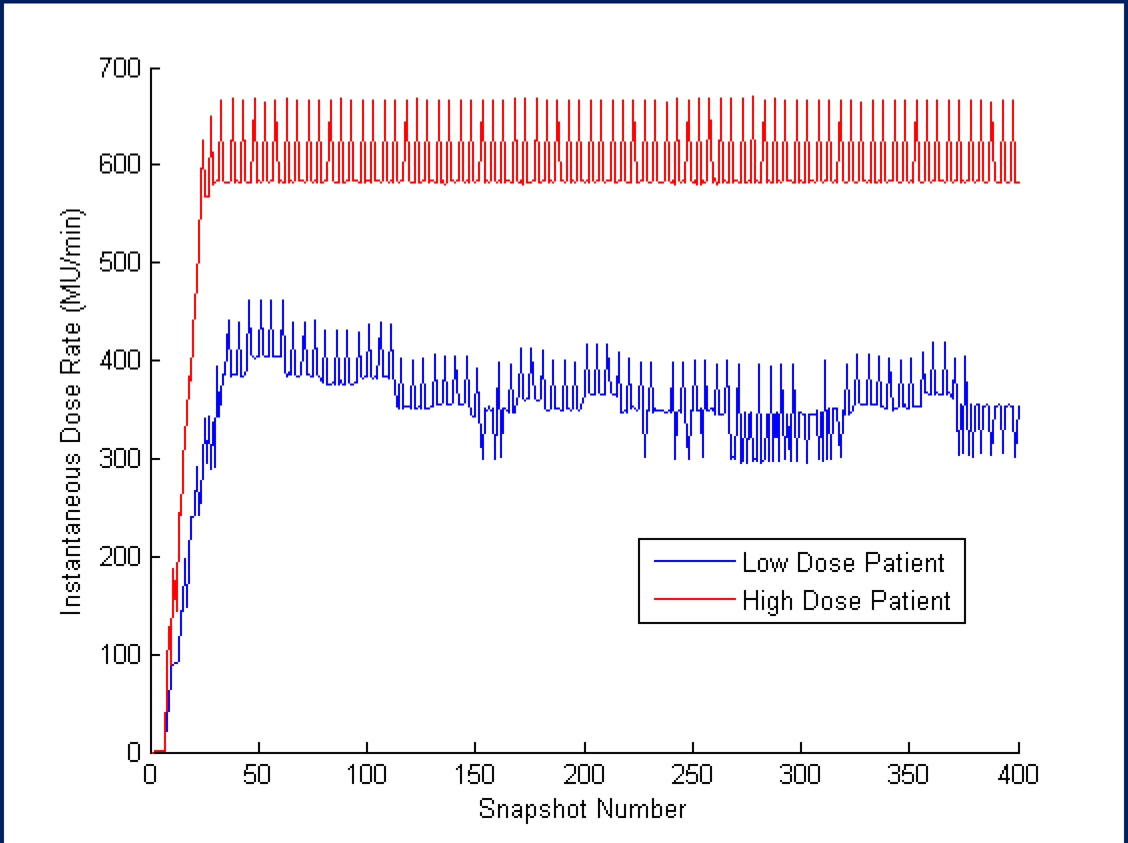
A. Mans, et al., “Catching erros with in vivo EPID dosimetry”, Med. Phys.(2010) 37 (6) 2638-2644

Summary

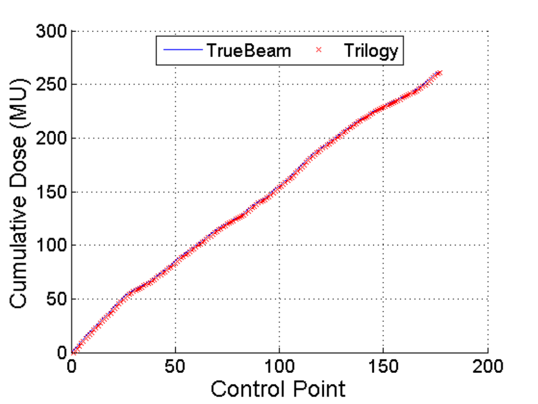
- Log files provide us rich information on delivery
- It does not require any additional detectors
- Useful to get real time access
- Need to make log file parameters more reliable

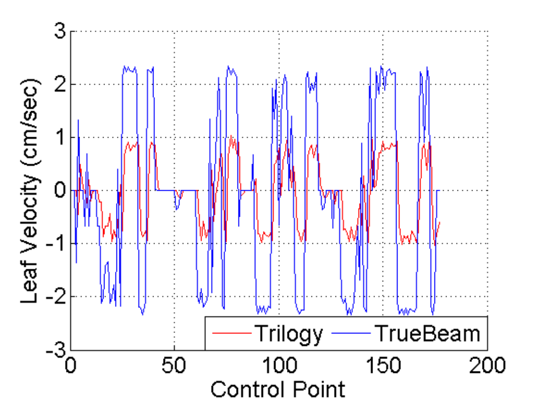

Thank You!

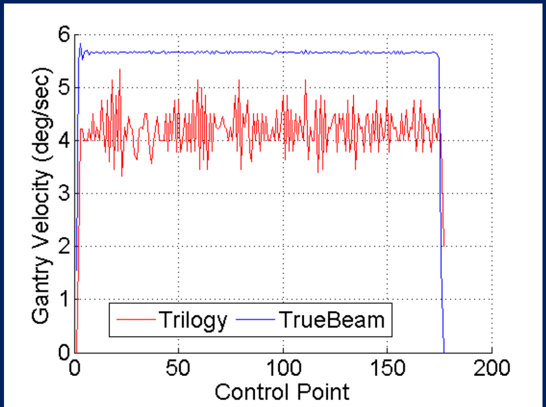
Instantaneous dose rate of TrueBeam - VMAT

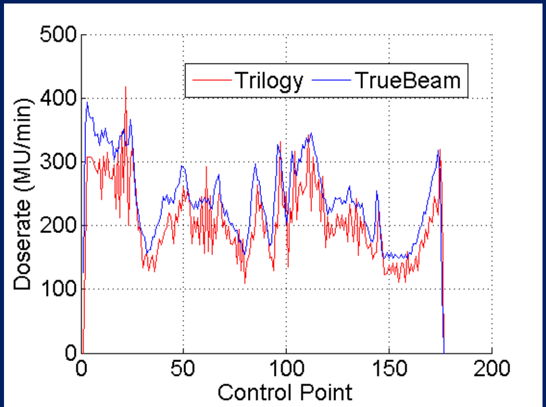


Comparison of Trilogy and TrueBeam via log files









RapidArc Enabled Clinac extreme mechanical limits

- Reference gantry speed – 360^0/65s
  - (2 - 5.5^0/s)
- Leaf speed – maximum 2.4 cm/s
- Dose rate max - 600 MU/min
- Dose per gantry angle
  - 1.8 MU/deg at max dose rate
  - 0.1 MU/deg minimum

RapidArc Enabled Clinac creates two sets of STT files

- One STT ---→ clinac control system gantry angle and Mu per control point
  - Linac log files record planned and delivered Gantry angle as a function of cumulative MU
- Second STT ---→ MLC controller which has MLC positions as a function of gantry angle
  - Machine Dynalog files record planned and delivered gantry angle, beam on flag, MLC leaf positions for all 120 leaves per every 50 ms time window

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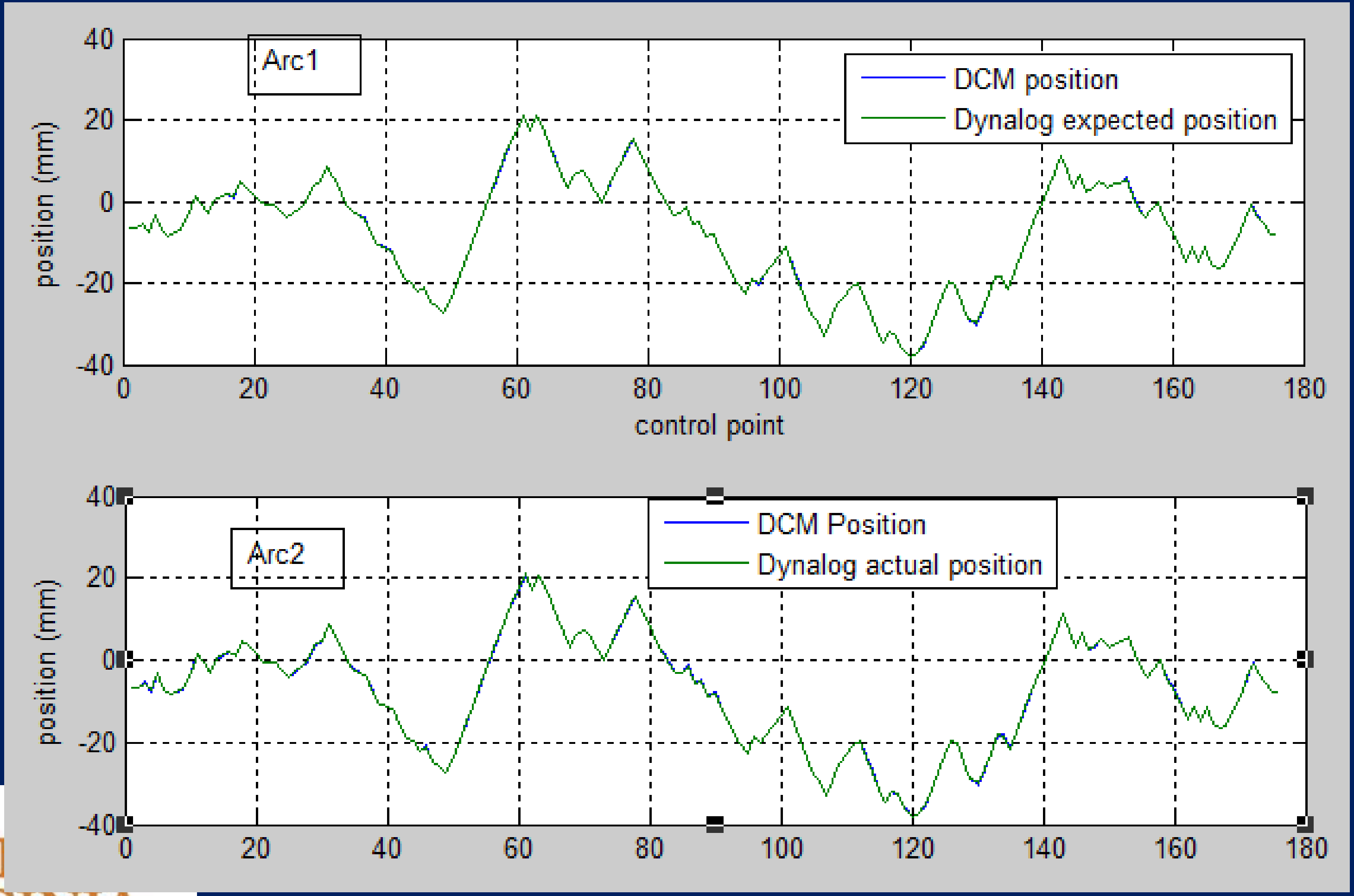
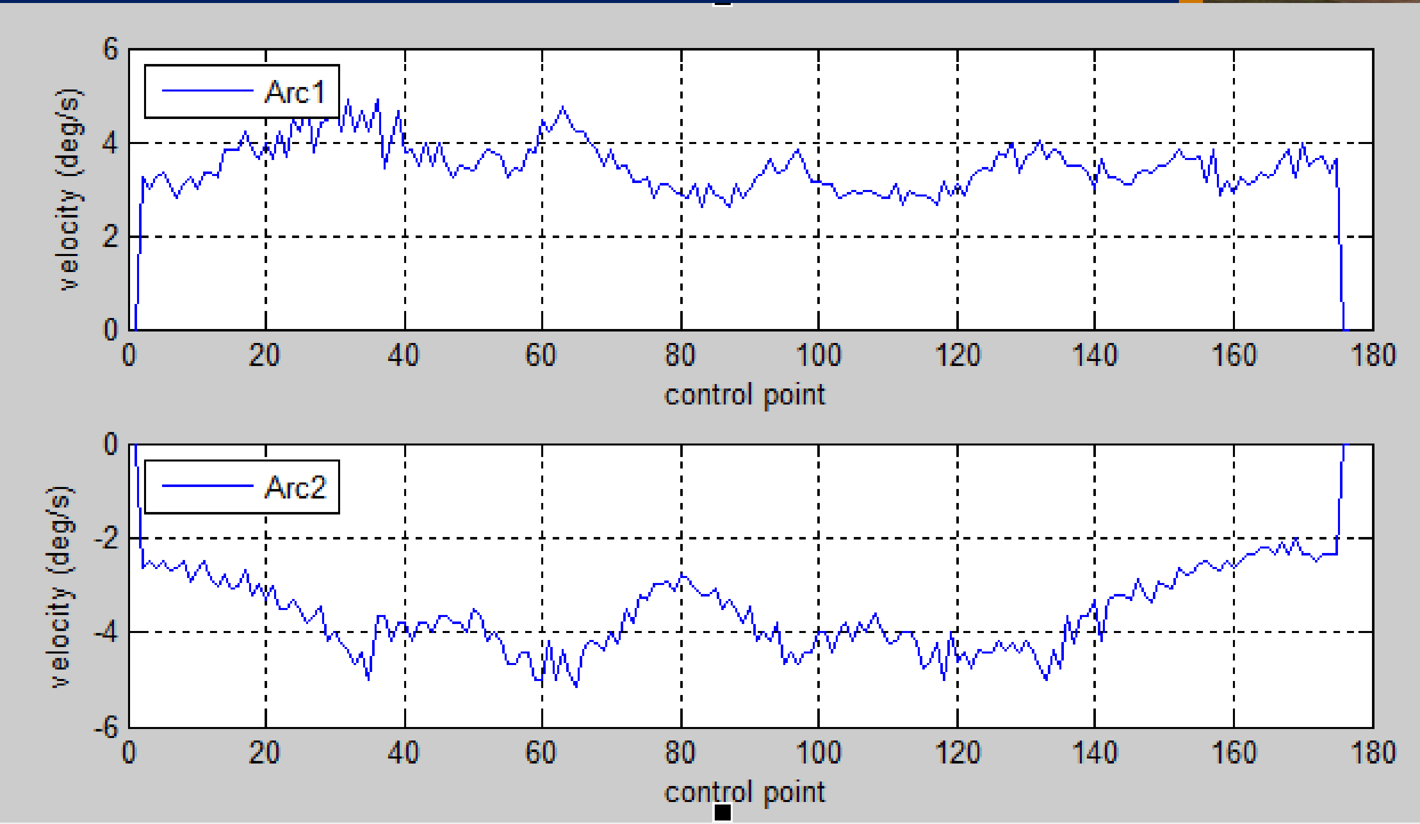
Planned and delivered average MLC leaf positions per each control point per each arc



Reconstructed delivered gantry speed for the two arcs



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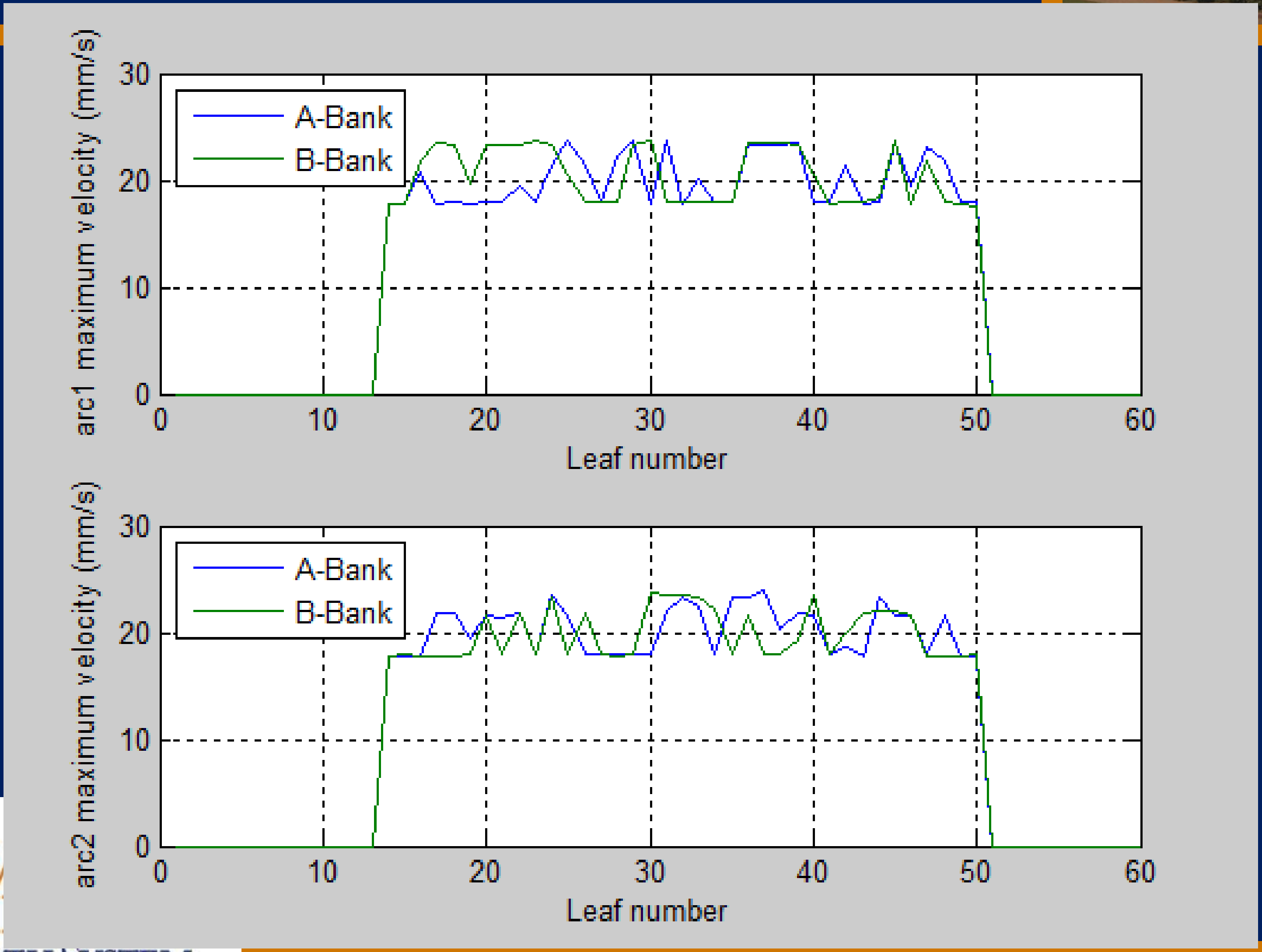
Reconstructed maximum leaf velocities per each leaf



Post Tx evaluation of motion affected dose delivery

- Challenging to deliver radiation to a moving tumor
- SBRT treatments with a few high dose fractions does not average motion effects
- A single IMRT delivery can have dosimetric variations up to 18% due to interplay effects [Jiang SB, Pope C, Jarrah KMA *et al.* "An experimental investigation on intra-fractional organ motion effects in lung IMRT treatments", Phys. Med. Biol. 48: 1773-1784 (2003)]
- Patients daily breathing variations from planning scan can also impact dose to ITV

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Current Methods

- 4D planning relies exclusively on initial 4DCT images, and initial breathing pattern – does not reflect the actual delivery
- No information on the interplay effects
- Need to contour the ITV in all phases
- No information to adapt the future plan

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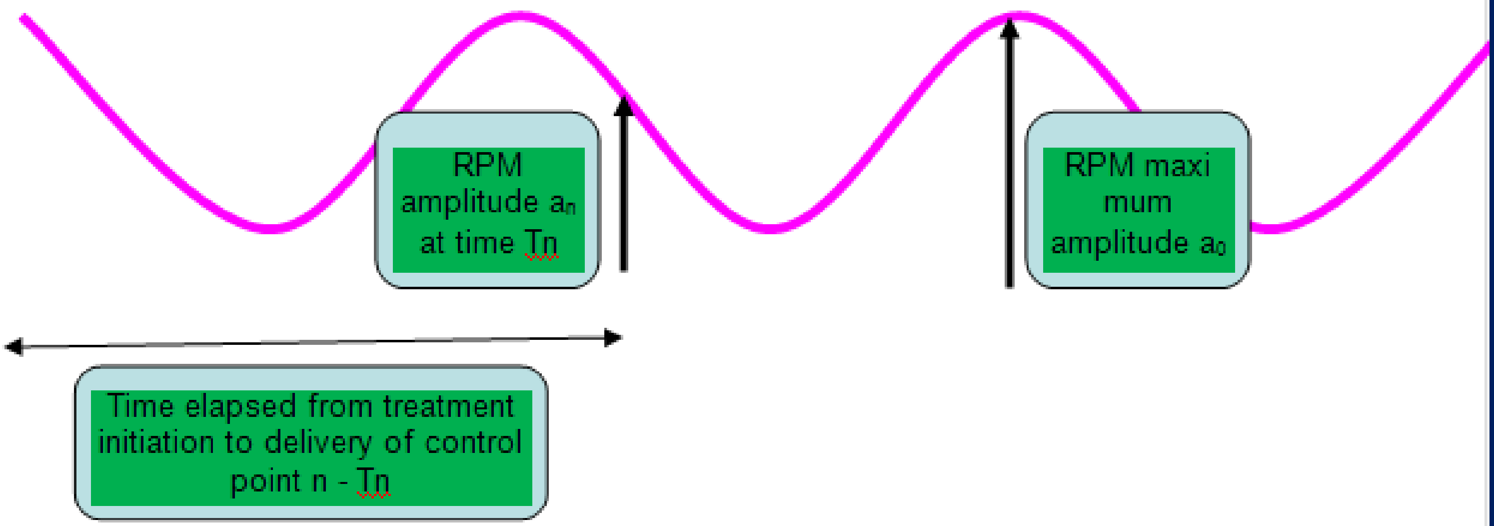
Internal Tumor Motion Amplitude At a Given Control Point



Tumor motion amplitude at delivery of control point n, A_n

A_n = 4DCT maximum tumor amplitude X RPM a_n/RPM a_0

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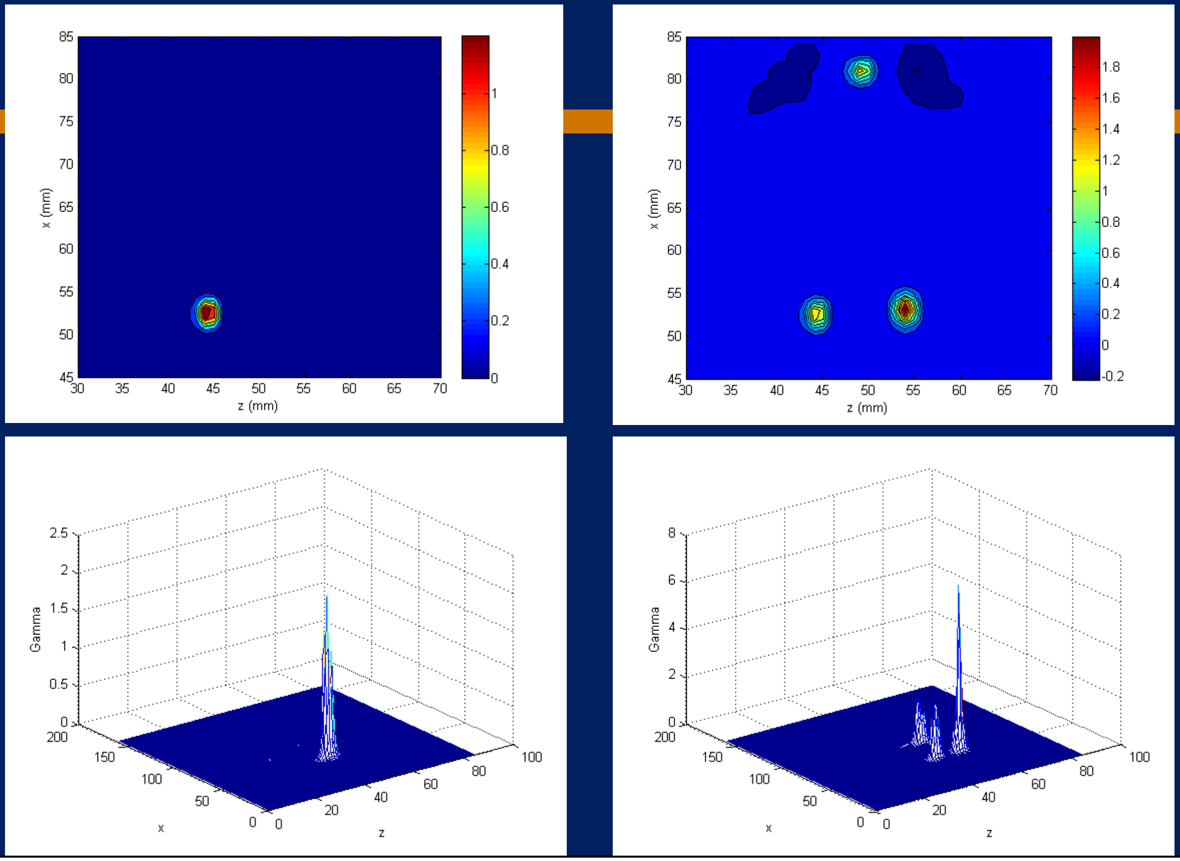
Method - Reconstruction

- Create the effects of tumor motion → move the active MLC's for a control point by its internal tumor motion amplitude at the time of delivery in the opposite direction to tumor motion
  - in the 2D plane of the MLC's;
  - I/S motion and a component of L/R, or A/P motion given the location of the gantry angle
- This delivered motion affected DICOM RT plan is then imported back to TPS
- Actual motion affected 4D dose map and dose volume histogram (DVH) for the tumor volume is recomputed.

Range of machine parameters evaluated and observed accuracy under RapidArc delivery

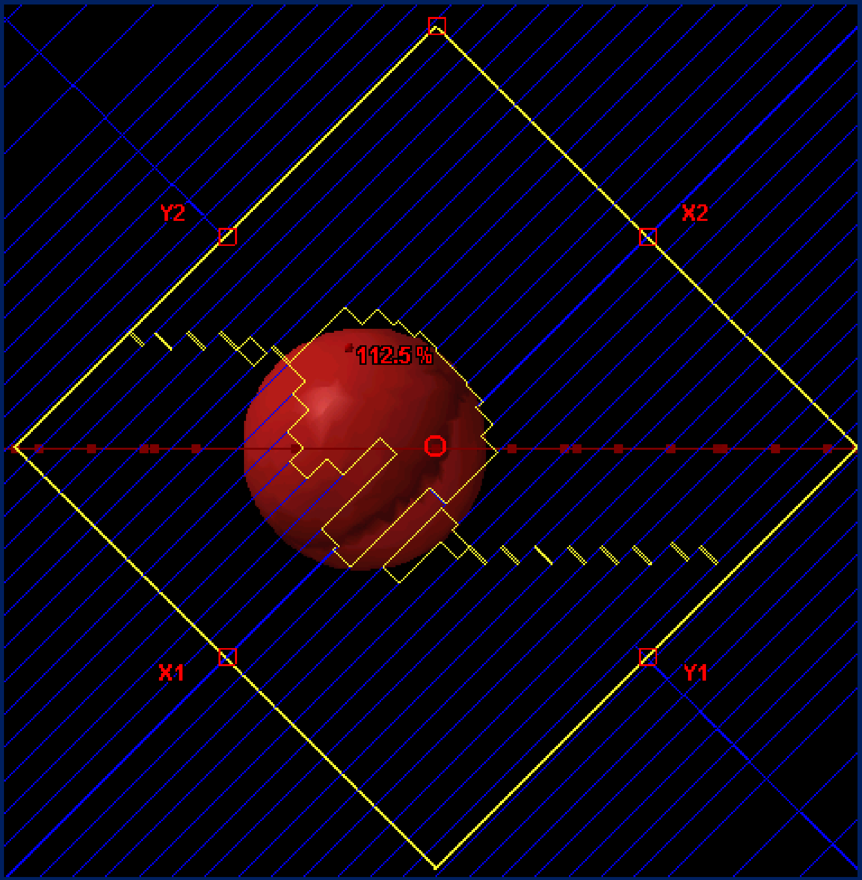
Patient	Plan type	Range of gantry speed (deg/s)	Maximum MLC leaf velocity (cm/s)	Dose rate (MU/min)	Maximum leaf position error (mm)	Maximum gantry postion error (deg)
1	Nominal	4.8 – 4.8	1.7	165–439	0.8	0.58
	Hi MLC velocity	4.8 - 4.8	2.1	144–371	1.15	0.93
	Slow gantry speed	2.1 – 4.8	1.7	386-600	0.84	0.62
2	Nominal	4.8 – 4.8	1.7	208-519	0.5	0.67
	Hi MLC velocity	4.8 – 5.2	2.0	216-490	0.65	0.68
	Slow gantry speed	2.0 – 5.1	1.3	474-600	0.35	0.42
3	Nominal	4.8 – 4.8	1.7	212-400	0.78	0.93
	Hi MLC velocity	4.8 – 4.8	2.1	207-457	1.02	0.90
	Slow gantry speed	2.3 – 4.7	1.3	600-600	0.32	0.55
4	Nominal	4.8 – 5.0	1.3	194-369	0.77	0.92
	Hi MLC velocity	4.8 – 5.0	2.1	180-349	1.06	0.95
	Slow gantry speed	2.5 - 5.0	1.3	600-600	0.53	0.57
5	Nominal	4.8 – 5.4	1.3	382-600	0.46	0.55
	Hi MLC velocity	4.8 – 5.4	1.8	398-600	0.94	0.58
	Slow gantry speed	2.8 – 5.4	1.3	600-600	0.35	0.48
6	Nominal	4.8 – 5.4	1.7	202-473	0.55	0.92
	Hi MLC velocity	4.8 – 5.4	2.4	181-458	0.95	0.8
	Slow gantry speed	2.2 – 5.4	1.3	600-600	0.41	0.55
7	Nominal	4.8 – 5.1	1.7	282-492	0.43	0.57
	Hi MLC velocity	4.8 – 5.1	2.4	260-500	0.88	0.9
	Slow gantry speed	2.7 – 5.1	1.3	600-600	0.35	0.48
8	Nominal	4.8 – 5.0	1.7	282-492	0.37	0.53
	Hi MLC velocity	4.8 – 5.0	2.4	319-507	1.17	0.63
	Slow gantry speed	2.8 – 5.0	1.3	600-600	0.32	0.45
9	Nominal	4.8 – 5.2	1.3	320 –550	0.35	0.6
	Hi MLC velocity	4.8 – 5.0	1.5	300 - 520	0.45	0.6
	Slow gantry speed	2.5 – 5.0	1.3	600 -600	0.32	0.6
10	Nominal	4.8 – 5.0	1.7	290 – 490	0.46	0.6
	Hi MLC velocity	4.8 – 5.0	2.1	300 – 500	0.63	0.5
	Slow gantry speed	2.7 – 5.0	1.3	600 - 600	0.4	0.6

Reconstructed dose difference /3D gamma maps

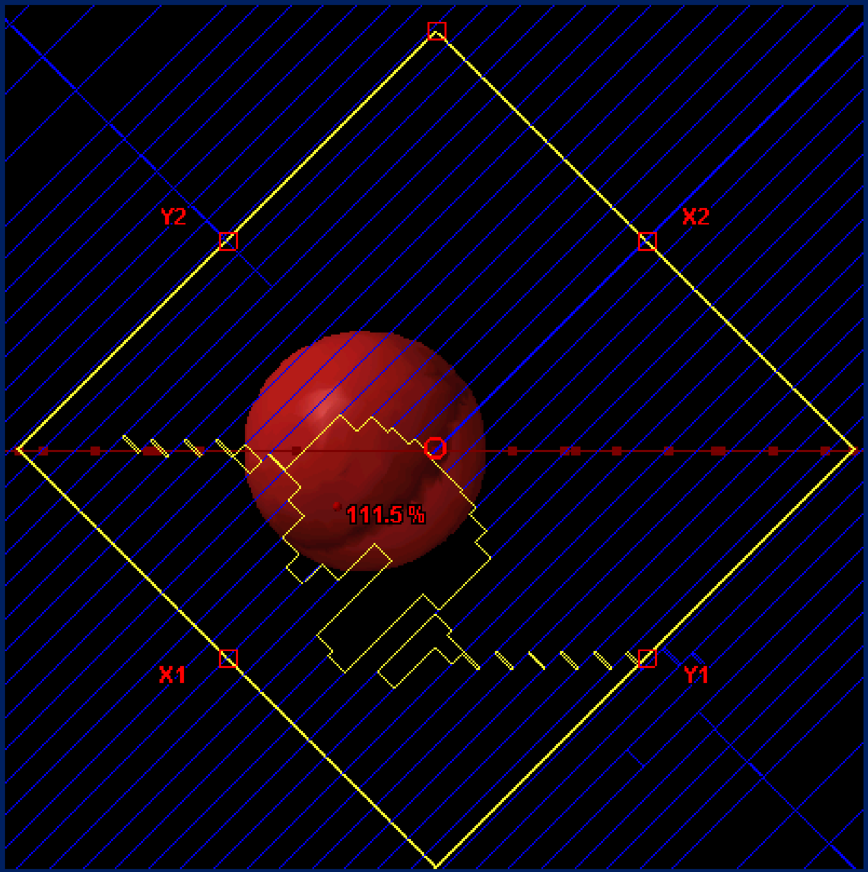


Reconstructed dose difference map in x z plane for a single control referred above for case (b) on left hand image and (c) on right hand image. In both cases z axis length corresponds to the thickness of MLC leaf (5mm), and x axis corresponds to the distance the leaf was intentionally moved (5mm). In the right hand plot three high dose areas correspond to where the three MLC s were pulled back from original positions, and two negative dose points correspond to where MLCs were pulled in by 5mm. Even a dose differnec of 1 – 2 cGy could be detected by this technique.

Motion Affected MLC Pattern for a Given Control Point (RapidArc)



Original plan



Motion affected plan

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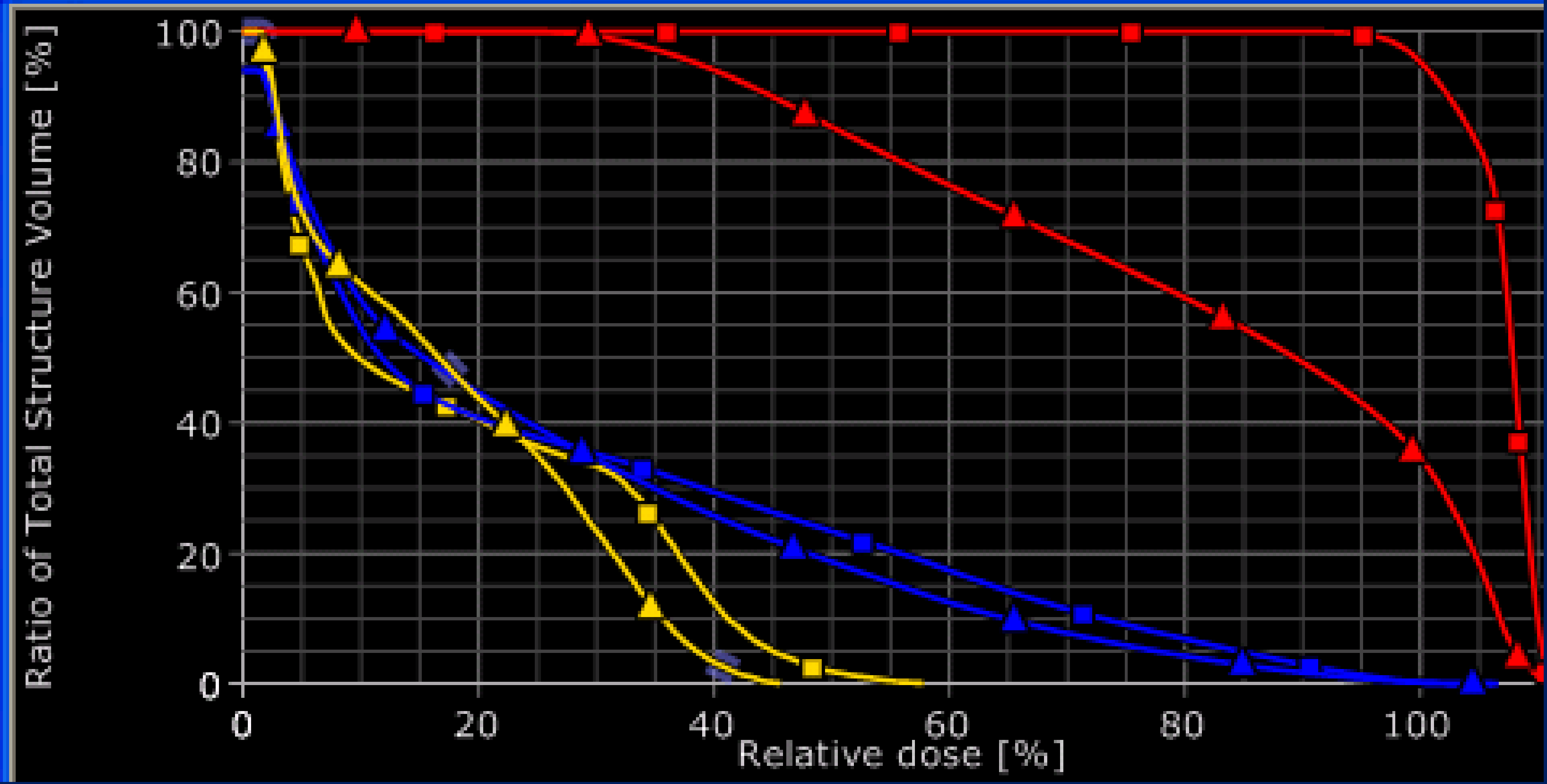
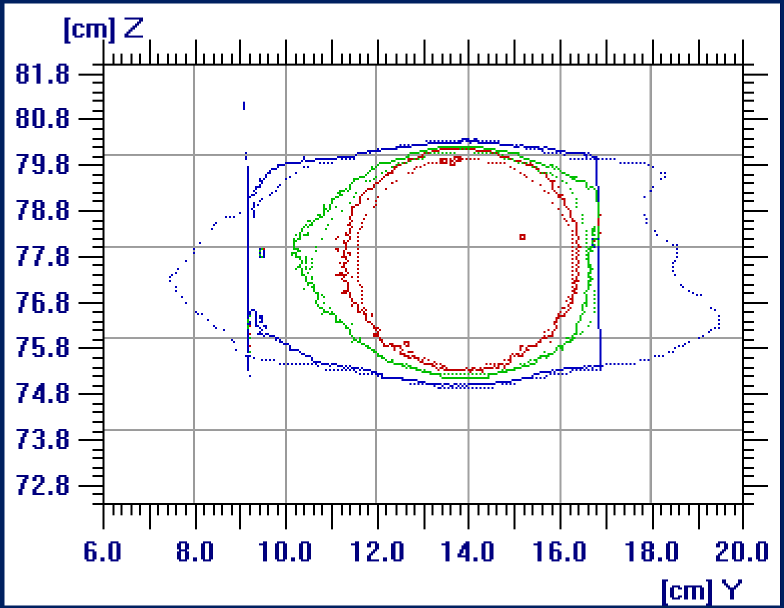


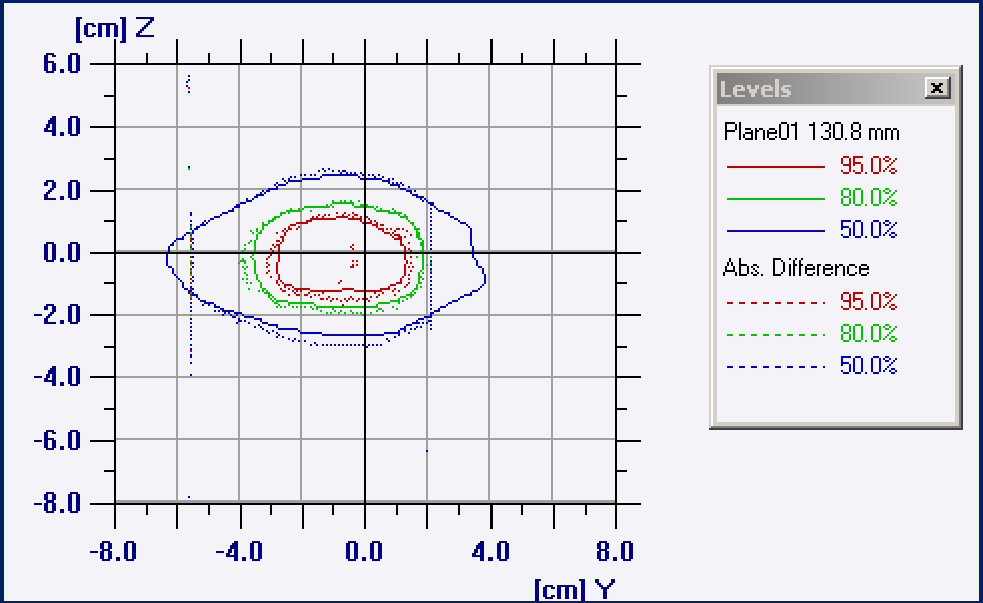
Dose volume histogram (4DVH) for a static tumor(squares), and 1D motion affected tumor (triangles) by a maximum motion amplitude of 2.5cm from a RapidArc plan. Red- ITV, yellow – cord, and blue - lungs

Comparison: Simulation to Measurement

Gafchromic film analysis



Original plan



Motion affected plan