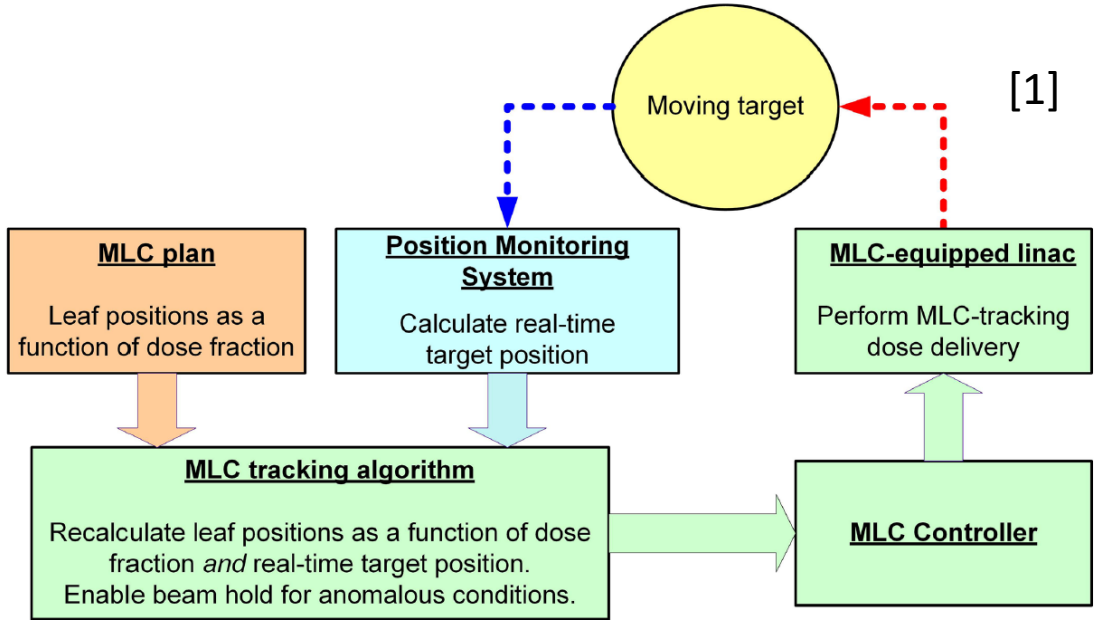
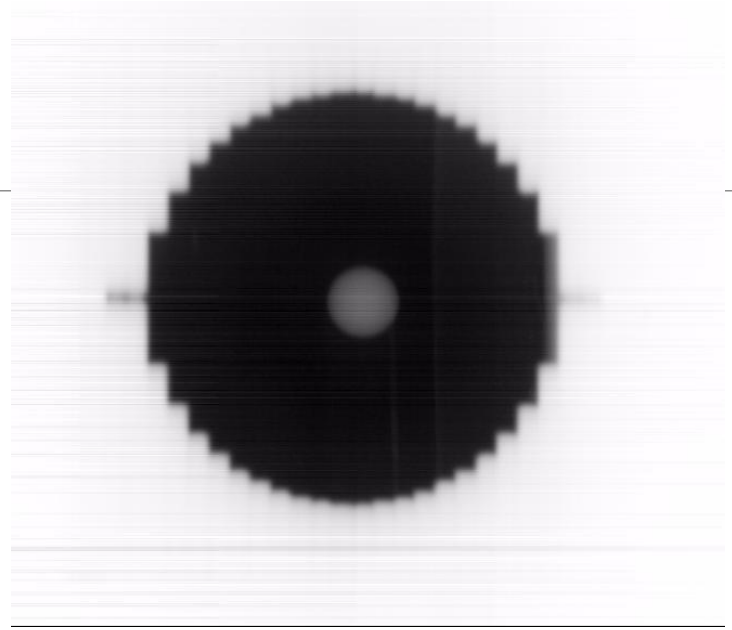
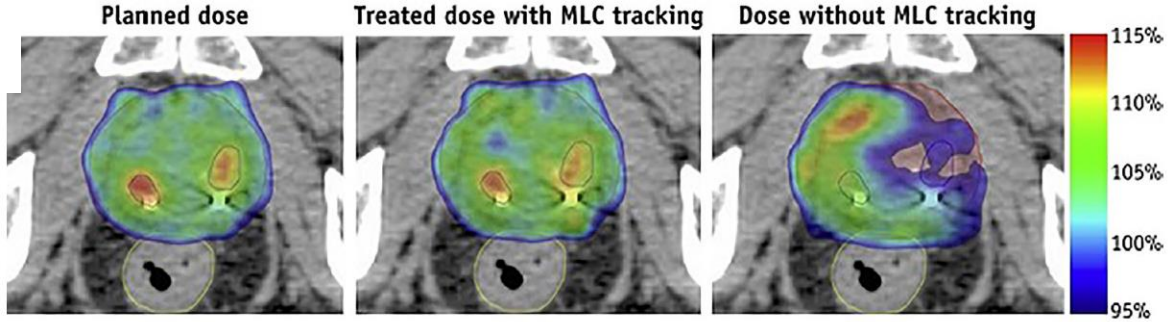
MLC tracking for motion management

Dr Emma Colvill

The basics







[1] Keall, P.J., et al. AAPM Task Group 264: The safe clinical implementation of MLC tracking in radiotherapy. Med. Phys. 2020

A very brief history of MLC tracking

1999 Conception (Keall)

2001-2010 integration with various systems

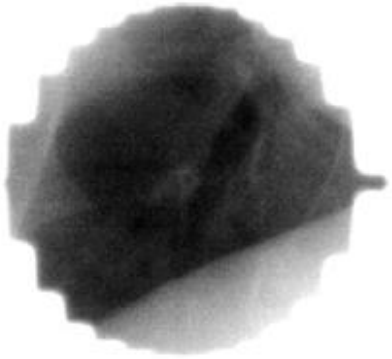
2010 Failure Mode Effect Analysis (Sawant)

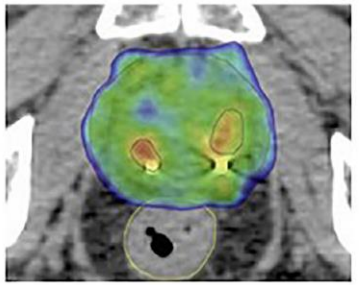
2012 Tracking in pigs (Poulsen)

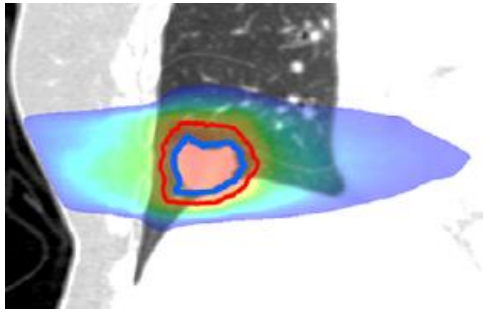
2013 Clinical tracking for prostate (Keall)

2015 Clinical tracking for lung (Booth)

2020 Taskgroup 264 report published (Keall)







Clinical applications to date

Prostate 2013 – non-commercial software – Varian Trilogy linac – Calypso tracking

Lung 2015 – non-commercial software – Varian Trilogy linac – Calypso tracking

Prostate 2016 – non-commercial software – Varian Trilogy linac – kV imaging

Radixact Tomotherapy – Professor X Allan Li - *Motion Tracking with MLC and Jaw During Tomotherapy Delivery*

- Few commercial options available – Tomotherapy and MR linac

- Varian and Elekta – research version available to research partners

Requirements for clinical implementation

- Real-time target position monitoring and MLC tracking system available
- Commissioned MLC tracking system with active QA program
- Sufficient description of the tracking method has been provided
- Staff are appropriately trained

Treatment decisions per clinical site/patient

- If pretreatment imaging is used, is the tumor closer to the critical structure than at planning? Will there be dosimetric consequences? What action should be taken?
- Is the motion different from that observed from simulation or previous treatments? What action should be taken?
- Were there any unanticipated events, near misses or errors? An example of an unanticipated event is a coughing fit where it may be prudent to pause the treatment.
- What information about the patient and tracking treatment should be stored/recorded?

Planning decisions per clinical site/patient

- Is there likely to be significant motion affecting dose delivered to tumor and/or normal structures during the treatment?
- What is the residual uncertainty between the real-time monitoring system and the tumor position?
- Is there likely to be target rotation or deformation?
- Should MLC tracking or target trailing be used?
- What margins are needed?
- Is there a critical structure that the target could move towards or vice versa and can a planning organ at risk volume (PRV) strategy spare the critical structure?
- Can the jaws be placed to spare the critical structure from different beam angles?
- What beam and collimator angles should be used (align leaves with major axis of motion)?
- Is an additional gating threshold needed (tracking volume)?
- Is there a periodic component to the motion and is prediction needed?
- How many adjacent leaves should be used?
- What is the fallback strategy in the case of MLC tracking failure?
- Are constraints on plan complexity needed?

[1] Keall, P.J., et al. AAPM Task Group 264: The safe clinical implementation of MLC tracking in radiotherapy. Med. Phys. 2020

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AAPM Task Group 264: The safe clinical implementation of MLC tracking in radiotherapy

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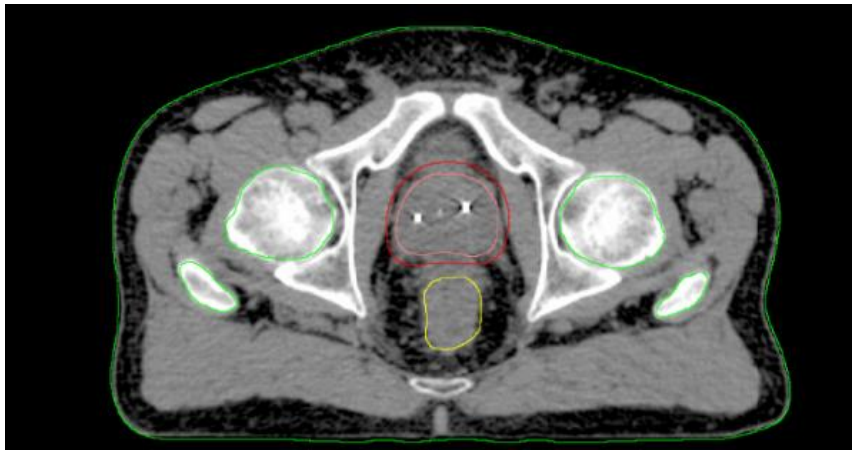
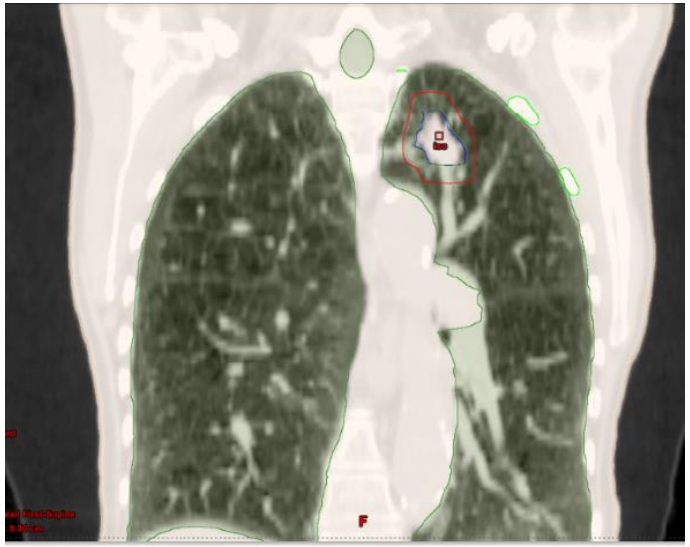
Treatment planning - Imaging

Not very different to non-MLC tracking protocols

Sites not effected by respiratory motion - 3D imaging is sufficient

Respiratory affected sites – 4D imaging is required
- generally 4DCT
- the target and OARs should be contoured on all phases
- if surrogates are used their stability should be assessed





Treatment planning

Non respiratory sites – 3D planning

May want to set maximum tracking distance and gate the beam

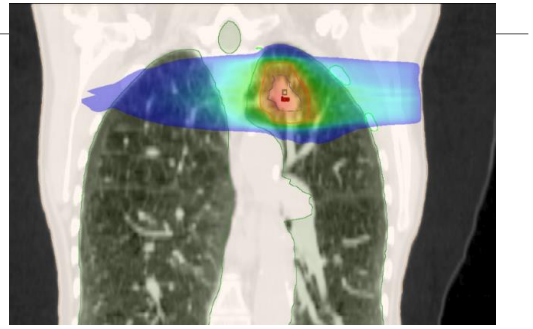
4D planning is not a requirement for respiratory motion affected targets

3D plan
- an extreme (exhale) phase GTV or a MIP
- a rigidly combined GTV

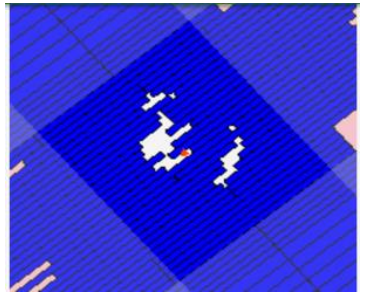
4D imaging provides information for margins - the range of motion of the target, including the time/phase dependence of the deformation/rotation, surrogate stability

Treatment planning

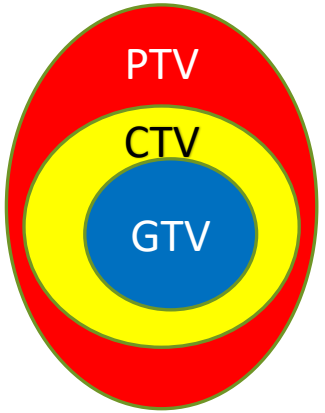
Factors which affect MLC tracking delivery:
- plan complexity
- leaf thickness
- target shape
- aligning the collimator angle with the major axis of motion
- complexity of the target motion



Margins for MLC tracking uncertainties account for:
- accuracy of the motion surrogate
- deformation (and rotation) of targets with respiration
- MLC tracking errors
- target delineation error



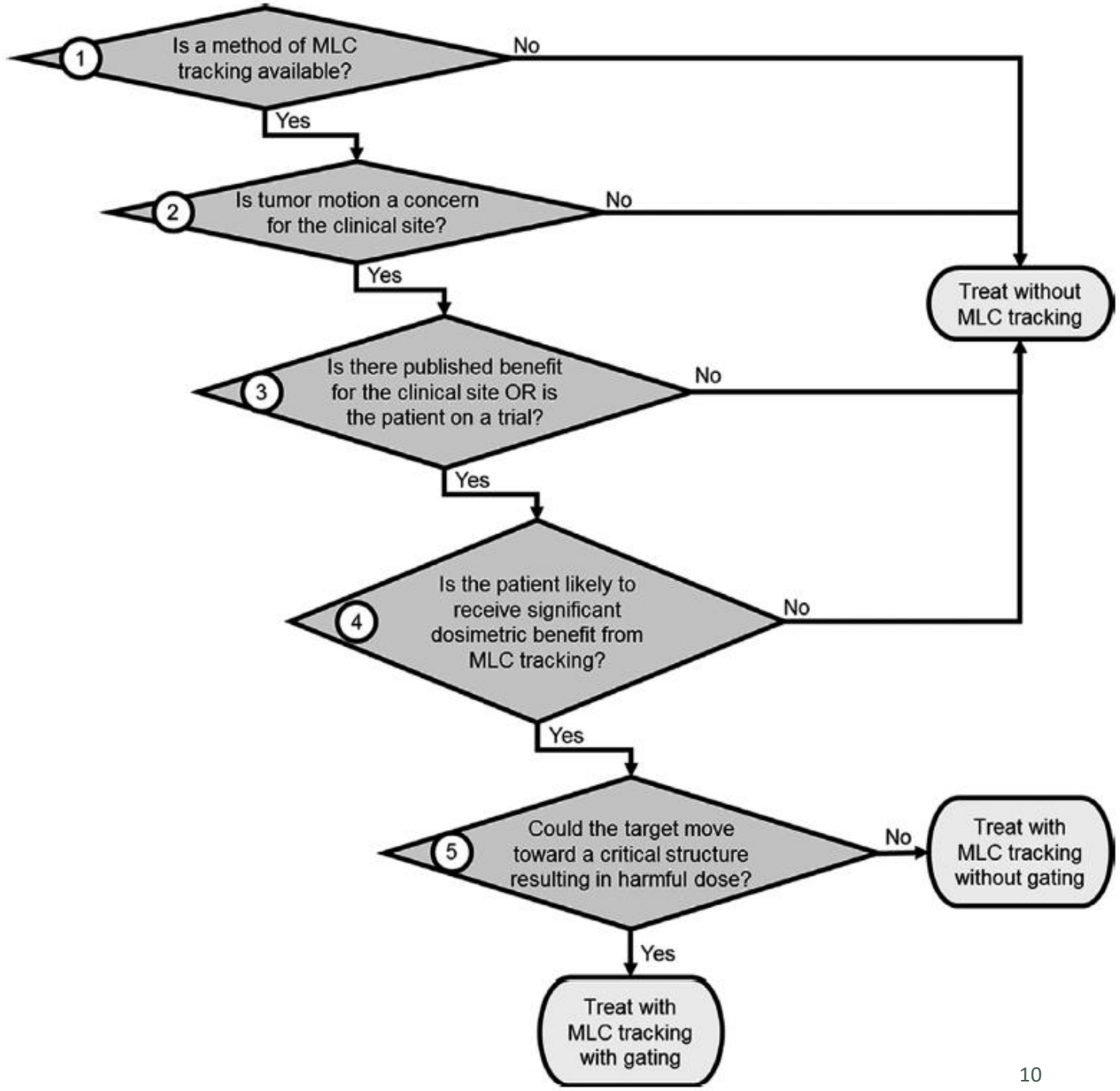
MLC tracking does not necessarily mean smaller margins
– some patients may not benefit from tracking
- Sydney lung tracking trial [1]
- The clinical decision pathway Task Group 264 [2]



[1] Caillet, V.,et al. Geometric uncertainty analysis of MLC tracking for lung SABR. Physics in Medicine & Biology 2020
[2] Keall, P.J., et al. AAPM Task Group 264: The safe clinical implementation of MLC tracking in radiotherapy. Med. Phys. 2020

Clinical decision pathway

Task Group 264



Treatment delivery

Similar set-up to non-MLC tracking treatments

- Patient positioning
- Volumetric imaging
- Adjust for inter-fraction shifts

During delivery

- the MLC tracking system will adapt without intervention
- check connectivity between subsystems
- check for motion outside any predetermined tracking range

After delivery the system should write tracking logs with target motion and leaf motion to the report and verify system

Real-time imaging requirements

1. The surrogate is established for the target and the uncertainty is known (typically ≤ 2 mm)

2. The accuracy of the position monitoring signal has been characterized (typically ≤ 1 mm).

3. The precision of the position monitoring signal has been characterized (typically ≤ 1 mm).

4. The frequency of the position monitoring signal measurement meets the definition of real-time (typically ≥ 3 Hz for targets affected by respiratory motion).

5. The average latency measurement meets the definition of real-time (typically ≤ 500 ms).

6. **The system is part of an active QA program independent from MLC tracking**

7. The risks of the position monitoring system should be understood and accepted.

Quality Assurance (QA)

- Overseen by a qualified medical physicist (QMP)

QA for MLC tracking should ensure:

- Spatial and dosimetric accuracy
- Efficient dose delivery
- Detection of and response to anomalous conditions

Pre-treatment – patient specific + System QA + Post-treatment – dose reconstruction

Failure mode and effect analysis-based quality assurance for dynamic MLC tracking systems

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Failure Mode Effect Analysis (FMEA)

1) Identifying each step in a process and charting a process tree

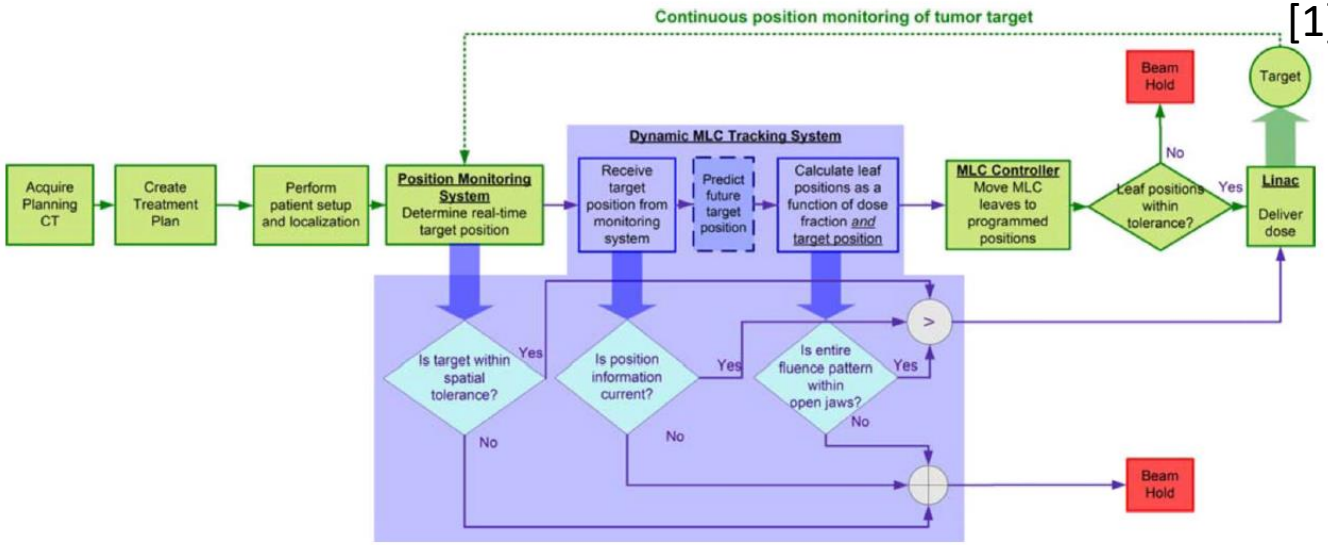
2) identifying potential modes of failure for each step

3) identifying the potential causes and the local as well as downstream effects of each failure

4) assessing the overall risk of each failure using three independent variables:

- The probability of occurrence *O*
- The severity of effect *S*
- The detectibility (probability of failure to detect) *D*

Risk Probability Number RPN=OxSxD



[1]

[1] Sawant A, Dieterich S, Svatos M, Keall P. Failure mode and effect analysis-based quality assurance for dynamic MLC tracking systems. Med Phys. 2010

Failure Mode Effect Analysis (FMEA)

Should be overseen by a QMP

Performed by a team – multiple physicists, a therapist, physician – external institutions

Should be revisited – new failure modes, new information on existing failure modes

AAPM Task Group 100 - risk analysis in quality management [1]

Original MLC tracking FMEA paper by Sawant [2]

Example documents currently in clinical use – supplement to Task Group 264 report [3]

[1] Huq MS, et al. The report of Task Group 100 of the AAPM: application of risk analysis methods to radiation therapy quality management. Med Phys. 2016
[2] Sawant A, Dieterich S, Svatos M, Keall P. Failure mode and effect analysis-based quality assurance for dynamic MLC tracking systems. Med Phys. 2010
[3] Keall, P.J., et al. AAPM Task Group 264: The safe clinical implementation of MLC tracking in radiotherapy. Med. Phys. 2020

System QA

Coordinate transform check

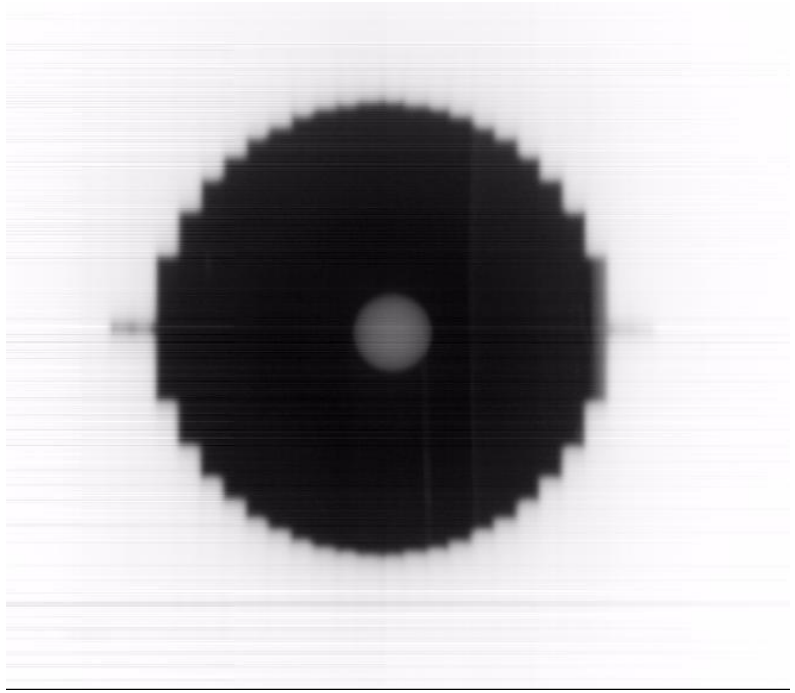
Overall system latency

Dosimetric accuracy – gamma results
with and without prediction

Efficiency

Anomalous conditions

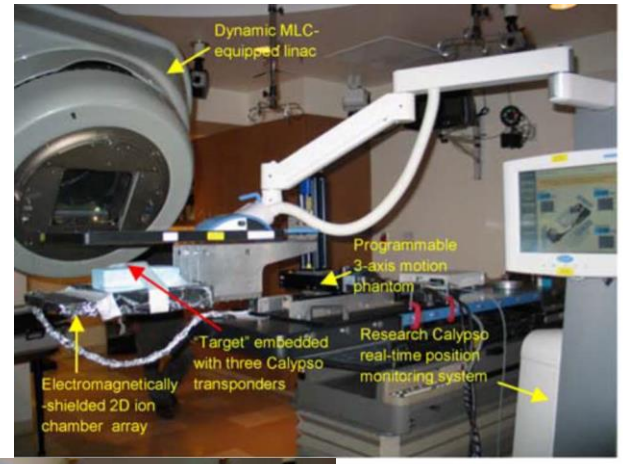
- Target outside tracking volume
- MLC aperture under jaws
- Communication failure (e.g. with motion monitoring)



System QA – yearly/monthly

Which test belong to commissioning/yearly QA and which to monthly?

- it depends on your process
- on the outcome of the FMEA

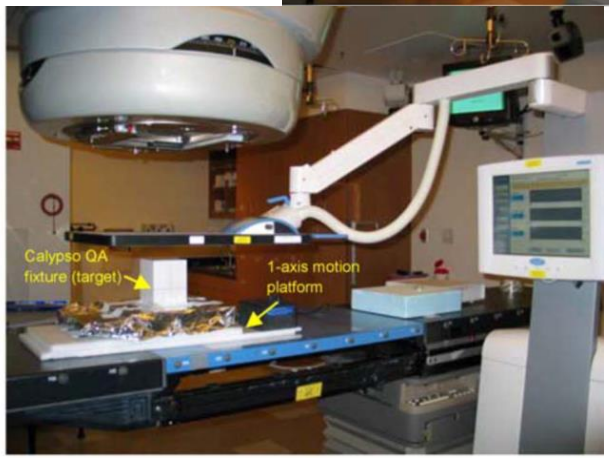


Commissioning/yearly

- 3D motion and dose measurements/set up
- Lesser ranked failure modes (RPN<125)
- ~3.5 hours

Monthly

- 1D motion and 2D dose measurements
- Higher ranked failure modes (RPN>125)
- ~30-60 minutes



[1] Sawant A, Dieterich S, Svatos M, Keall P. Failure mode and effect analysis-based quality assurance for dynamic MLC tracking systems. Med Phys. 2010

Patient specific QA

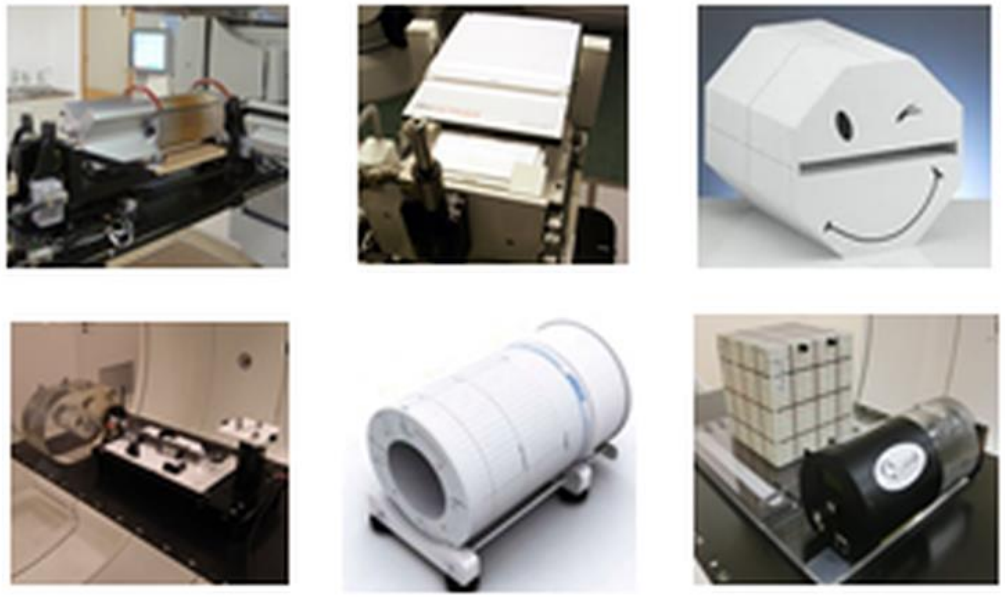
Can the plan be delivered with MLC tracking with the likely motion of the patient?

Pre-treatment end-to-end dosimetry of the MLC tracking treatment plan

Requires 4D motion platform which can move a dosimeter with realistic motion for QA delivery

There are many plan factors which can impact the MLC tracking delivery

Do not want to encounter plan related issues with the patient on the table



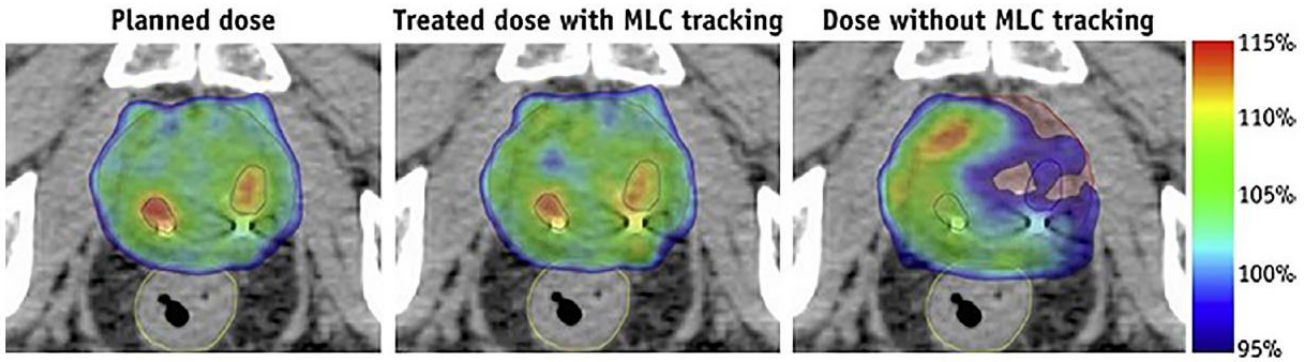
Post treatment dose reconstruction

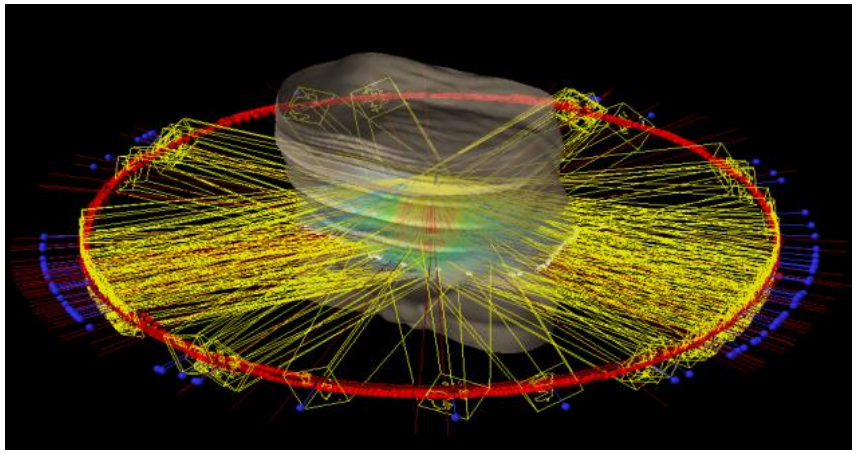
Using the tracking log files recorded from each treatment

Delivered dose can be calculated, often using the treatment planning system

The leaf positions and the target positions are known

Ideally prior to the next treatment





Takeaways

- Require operational imaging system with QA processes separate to MLC tracking

- Thorough understanding of the MLC tracking system and it's uncertainties

- Imaging and planning processes are not too dissimilar to non-MLC tracking

- QMP lead FMEA based QA-program – which is revisited
    - patient specific pre-treatment QA
    - system QA
    - post-treatment QA

- MLC tracking is not for every patient or treatment site

References

Keall, P.J., et al. *AAPM Task Group 264: The safe clinical implementation of MLC tracking in radiotherapy.* Med. Phys. 2020

Huq MS, et al. *The report of Task Group 100 of the AAPM: application of risk analysis methods to radiation therapy quality management.* Med Phys. 2016

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Thank you!