# Quality Assurance for Advanced Digital Linac Implementations

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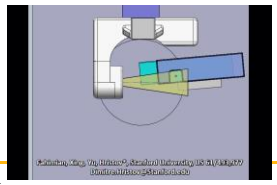
## New treatment delivery techniques: Couch motion

- Advanced delivery techniques achieve dosimetric improvements through extensive couch motion [1-3]
- Quality assurance regarding accurate and safe control of the couch is essential



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[1] Rodrigues, A., et al., PMB 2013
[2] Fahimian, B., et al Radiother Oncol, 2013.
[3] Dong, P., et al., IJROBP 2012



## Current Status on Couch Motion QA

- TG 142 Annual recommendations

| | | | |
|---|---|---|---|
| **Mechanical** | | | |
| Collimator rotation isocenter | | ±1 mm from baseline | |
| Gantry rotation isocenter | | ±1 mm from baseline | |
| Couch rotation isocenter | | ±1 mm from baseline | |
| Electron applicator interlocks | | Functional | |
| Coincidence of radiation and mechanical isocenter | ±2 mm from baseline | ±2 mm from baseline | ±1 mm from baseline |
| Table top sag | | 2 mm from baseline | |
| Table angle | | 1° | |
| Table travel maximum range movement in all directions | | ±2 mm | |
| Stereotactic accessories, lockouts, etc. | NA | NA | Functional |
| **Safety** | | | |
| Follow manufacturer's test procedures | | Functional | |

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## Current Status on Couch Motion QA

- TG 142 Annual recommendations

Limited in scope of treatment delivery + couch motion

| Mechanical | | | |
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| Follow manufacturer's test procedures | | Functional | |

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## Outline

- Mechanical accuracy (Stanford) [1]
  - Orchestrated and simultaneous movements of couch, gantry, multi-leaf collimator (MLC)
- Safety (UCLA)
  - Precise Linac collision modeling [2]
    - Complexity of non-coplanar beam angles
    - Collision avoidance between gantry, couch, and patient
  - In room real-time 3D camera

[1] Yu VY, Fahimian BP, Xing L, et al, Med Phys 41:081712, 2014

[2] Yu VY, Tran A, Nguyen D, et al, Med Phys 42:6457, 2015

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## Mechanical Accuracy

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- Couch positional accuracy (4π, TMAT, DEAR)
  - Translations
  - Rotation
- Couch velocity constancy (TMAT, DEAR)
  - Translations
  - Rotation
  - Dose rate variation
- System accuracy during synchronous motion axes movements (TMAT, DEAR)
  - Couch + Gantry + MLC
- MLC Tracking (TMAT, DEAR)

Yu VY, Fahimian BP, Xing L, et al, Med Phys 41:081712, 2014
See supplementary material at http://dx.doi.org/10.1118/1.4932631 for XML scripts of all tests

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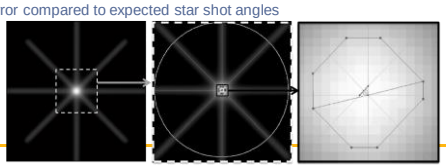
## Rotational accuracy: Couch Star Shot Test

- 0.5 cm x 10 cm rectangular beam with jaws
- Statically delivered 4 times, 45 degree couch rotation between each delivery
- Orthogonal distance between beam intersections
- Angular error compared to expected star shot angles



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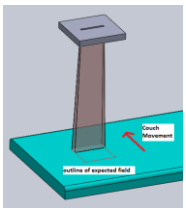
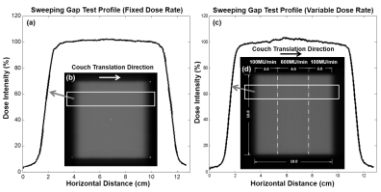
## Continuous Couch Translation Constancy: Sweeping Gap Test

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Yu VY, Fahimian BP, Xing L, et al, Med Phys 41:081712, 2014

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- Dose variation introduced by changes in couch velocity and dose rate mostly do not exceed 2%
- Longitudinal variable dose rate, 97.2% of points are within 2%

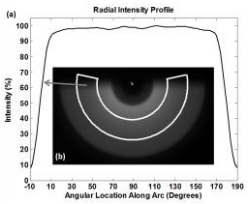
| Couch movement direction | Standard deviation | Maximum deviation |
|---|---|---|
| Deviation relative to the mean (fixed dose rate) (%) | | |
| Lateral | 0.37 | 1.04 |
| Longitudinal | 0.52 | 1.10 |
| Deviation relative to the mean (variable dose rate) (%) | | |
| Lateral | 0.95 | 1.98 |
| Longitudinal | 1.12 | 2.42 |



Yu VY, Fahimian BP, Xing L, et al, Med Phys 41:081712, 2014



## Continuous Couch Rotation Uniformity




- Rotate couch 180 degrees while continuously delivering off-centered rectangular beam
- Intensity profile sampled from a 2 cm wide arc

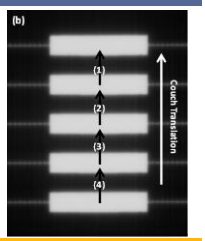


Yu VY, Fahimian BP, Xing L, et al, Med Phys 41:081712, 2014



## Synchronous Motion Execution: MLC Walkaway + Gantry Turnaway Test

- A test that creates an analyzable dose distribution with simultaneous movement of the gantry, couch, and MLC



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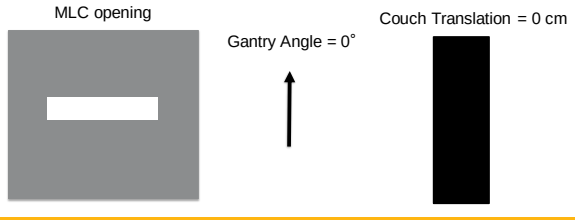


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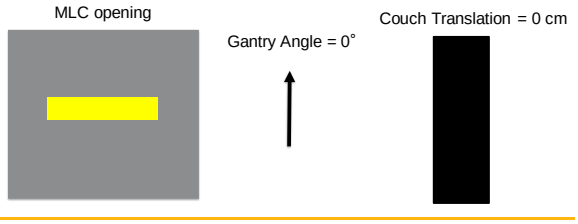


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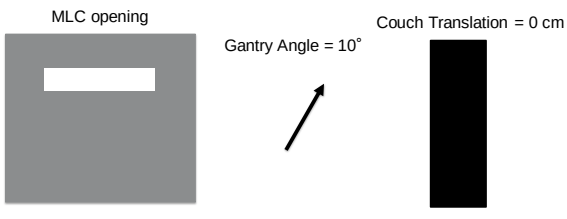


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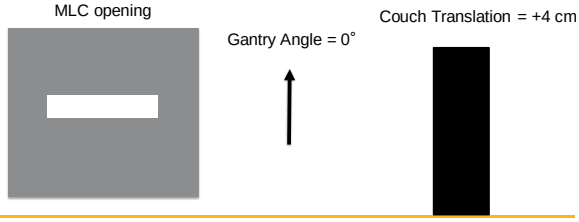


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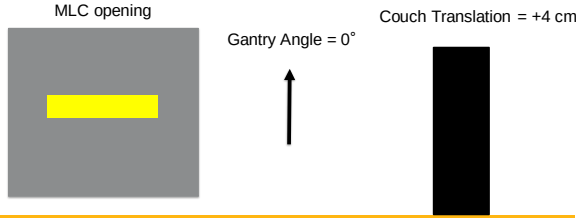


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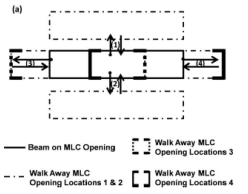


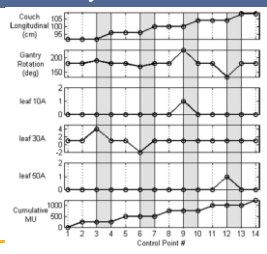


Yu VY, Fahimian BP, Xing L, et al. Med Phys 41:081712, 2014

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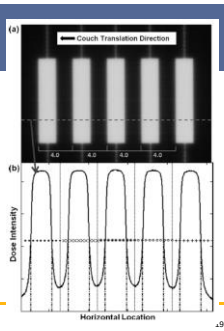
## Analysis

- Extract intensity profile of each pair of leaves
  - Midpoint between two successive leakage lines
  - measure distance between successive locations of the left edge of each stripe
- Measure distance between left edge of all stripes
  - Half max location defined as stripe edge

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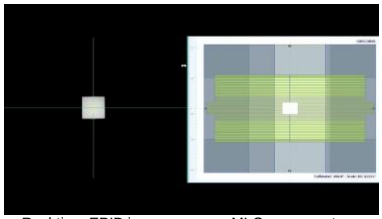
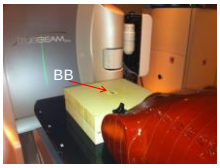
## MLC Tracking



Real-time EPID image MLC movement




- BB fixed on couch
- Move couch and MLC simultaneously to track BB

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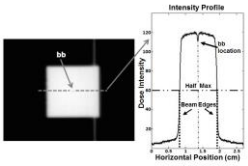
## MLC Tracking




| | Left to fiducial[a] | | Right to fiducial[b] | | End to end[c] | |
|---|---|---|---|---|---|---|
| Couch direction | Mean | std | Mean | std | Mean | std |
| Lateral | 1.950 | 0.020 | 2.047 | 0.015 | 3.997 | 0.006 |
| Longitudinal | 1.970 | 0.010 | 2.033 | 0.006 | 4.003 | 0.006 |

- Fiducial to beam edge distances from all EPID images
- Maximum deviation 0.06 cm

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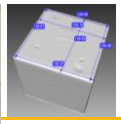
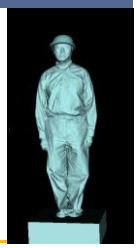
# Safety



## Collision Modeling

- 3D scanning of phantom and human subject
- 3D scanner verification
  - Scanning of phantom with known dimensions
  - ~0.5 mm accuracy

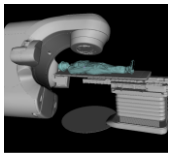


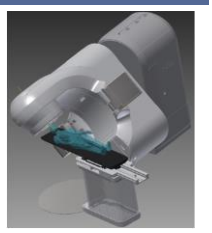




## Collision Modeling

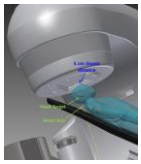
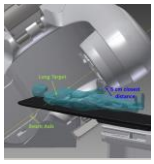
- Computer-aided Design (CAD) model of TrueBeam
  - Provided by Varian medical systems





## CAD model verification

- Distance measurements of 300 different linear accelerator orientations with phantom on couch
  - Treatment-site specific (head, lung, prostate)

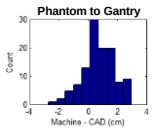


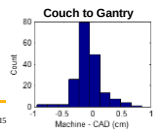

Yu VY, Tran A, Nguyen D, et al, Med Phys 42:6457, 2015 25

## Analysis of measurement discrepancies

- Maximum measurement discrepancy = 3 cm
  - Set up reproducibility of phantom
  - Flexible phantom extremities
- Gaussian fitting of distance offset data
- Safety margin estimation with determined Gaussian distributions
  - 99.99% confidence in collision avoidance

| Couch to Gantry (cm) | | | Phantom to Gantry (cm) | | |
|---|---|---|---|---|---|
| Head | Lung | Prostate | Head | Lung | Prostate |
| 1.07 | 0.89 | 1.87 | 2.83 | 3.45 | 4.93 |



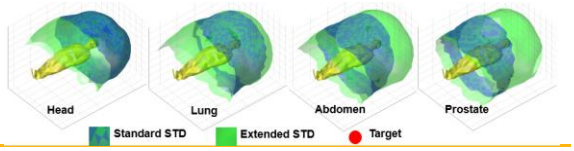






Yu VY, Tran A, Nguyen D, et al, Med Phys 42:6457, 2015 26

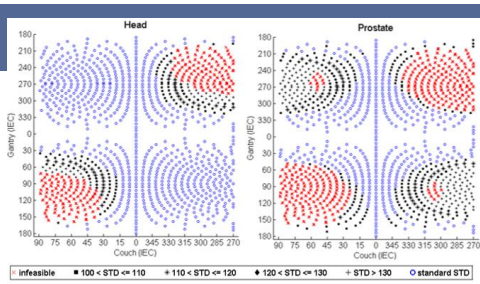
## Site specific collision-free beam solution space

- Exhaustive search from 1162 candidate beams
  - With human subject model on couch
  - Incorporating determined safety margins
- Collision-free beam solution space for various sites






Yu VY, Tran A, Nguyen D, et al, Med Phys 42:6457, 2015 27




Successful guidance of automated delivery of 20 non-coplanar beams within 15 minutes

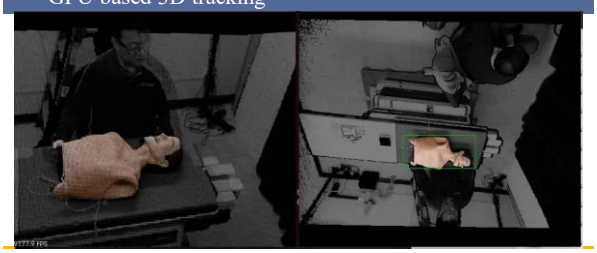


Yu VY, Tran A, Nguyen D, et al. Med Phys 42:6457, 2015 28

## In Room 3D Camera



## GPU based 3D tracking



## Collision Object Detection



## Result summary and comparison

| Mechanical | | | | |
|---|---|---|---|---|
| **Couch velocity constancy** | **New test results** | **TG-142** | **Suggested guidelines** | **Applicable techniques** |
| Translational fixed dose rate | 1.10% | X-ray flatness | <1% from baseline | TMAT, DEAR |
| Translational variable dose rate | 2.40% | X-ray flatness | <1% from baseline | TMAT, DEAR |
| Rotation | 1.60% | N/A | | TMAT, DEAR |
| **Couch static positioning** | | | | |
| Translational | 0.1 mm | picket fence test | <1mm | 4π, TMAT, DEAR |
| Rotational | 0.3° | MLC spoke shot | <1° | 4π, TMAT, DEAR |
| **Synchronous motion (couch + MLC + gantry)** | 0.3 mm | N/A | | TMAT, DEAR |
| **MLC Tracking with couch motion** | 0.6 mm | N/A | | TMAT, DEAR |
| **Safety** | | | | |
| **Collision clearance test** | < 3cm | N/A | | 4π, TMAT, DEAR |



## Future Work

- Most QA procedures emphasize on accuracy in isocenter placement
  - 4π and TMAT utilizes extended STD of up to 180 cm
  - 0.3° couch rotation error can correspond to translational error of up to 4.2 mm
- Patient motion induced by couch motion
- Patient specific collision modeling
  - Incorporation of full body 3D scanning as part of pre-treatment imaging
- Delivery technique based end-to-end testing

## Conclusions

- Extensive QA procedures should be developed and utilized to accommodate treatment techniques with extensive couch motion
- Modern digital Linacs is capable of delivering dynamic treatment technique involving complex couch motion with high mechanical and dosimetric accuracy
- Created virtual Linac model is capable of accurately predicting deliverable beams and guiding fully automated non-coplanar treatment delivery



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