Use of EPIDs for Non-Routine Linac QA

Bin Cai PhD

Department of Radiation Oncology
Division of Medical Physics

Washington University in St. Louis
School of Medicine

Disclosure

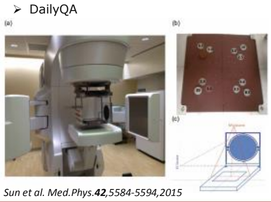
- Parts of this project received support from Varian Medical System.

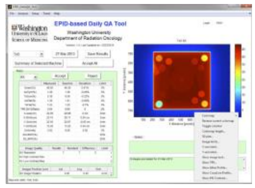
Learning Objectives

- Learn the recent development of EPID based Non-routine quality assurance (QA).
- Be aware of the limitations of the new implementation.

EPID based routine QA

- Many publications have demonstrated EPID can be used as a reliable and effective tool for some routine Linac QA.
  - DailyQA



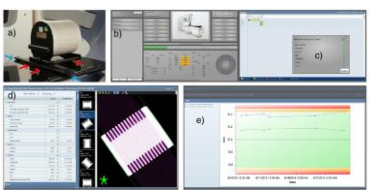


Sun et al. Med.Phys. ***42***, *5584-5594,2015*

Washington University School of Medicine in St.Louis
Department of Radiation Oncology
Division of Medical Physics

EPID based routine QA

- Machine performance check (MPC)



Clivio et al. Radiation Oncology (2015) 10:97 tc. Med.Phys. ***42***, *5584-5594,2015*

Washington University School of Medicine in St.Louis
Department of Radiation Oncology
Division of Medical Physics

Benefit of EPID based QA

- EPID available on Linac – lower cost
- Possibility for automation – higher efficiency, reduce human errors
- Enable the standardization – both delivery and analysis
- Opportunity for machine benchmarking

Image courtesy Varian.com and Elekta.com

Washington University School of Medicine in St.Louis
Department of Radiation Oncology
Division of Medical Physics

Recent development

- Efforts have been made to design and expand EPID based measurement to non-routine Linac test and QA.
- Non-routine QA
  - Less frequently performed
  - Unique specifications
  - Mainly for verification and modeling purpose
  - Baseline for future measurement
- Examples:

Linac Acceptance Test, measurement after a major repair, beam dosimetry verification, .etc.

Acceptance test

- EPID Based Rapid Acceptance Tests
- Aim: To develop a process utilizing the onboard kV and MV EPIDs to perform rapid acceptance testing (AT) on Varian Linac

  which:
  - Minimize the dependence on 3rd party tools & user expertise and
  - Significantly reduce the time required to perform the AT
  - Enables simultaneous establishment of lifelong routine QA/QC leveraging EPID, automation & cloud-based data processing

Yaddanapudi et al., Med. Phys. 44 (7), 2017

EPID based ATP

- Approaches:
  - The conventional AT tests and tolerances was used as a baseline guide – 45 tests that call for customer demos.
  - EPID based tests are proposed to perform as much tasks as possible
  - The procures were carried out on Varian Truebeam utilizing XML controlled machine motion and EPID images– mechanical and dosimetric tests
  - The proposed process was evaluated on one Linac at WashU and one Linac at UCSD

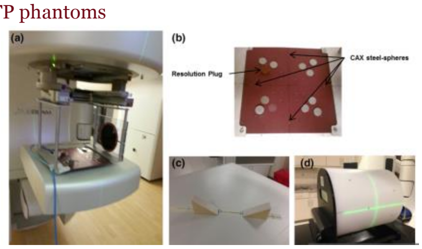
Test	Tools: Testing methodology	
	Conventional AT	**EPID-based AT**
Gantry rotation	Precision level: Gantry axis of rotation is important and should ensure good stability.	Machine Performance Check (MPC) application is an automated sequence that acquires 39 images (kV and MV) with and without *IsoCal* phantom in the beam. MPC uses radio-opaque markers that are embedded in the *IsoCal* phantom and analyzes these images for angular precision of gantry collimator and couch. MPC also measures couch position accuracy and translations accuracy (§II.C).
Collimator rotation	Graph paper and precision level: Central axis should be aligned with the axis of rotation, as it is an important aspect of any treatment unit and is checked to ensure it is within tolerance.	
Couch rotation	Graph paper: Collimator axis of rotation, gantry axis of rotation and the treatment couch axis of rotation should intersect in a point and this is verified.	
Couch positional verifications	Graph paper: The couch positional accuracy in the vertical, longitudinal and lateral directions is verified.	
Isocenter verification with *IsoLock*	*IsoLock* system: Radiation isocenter is primarily determined by the intersection of the three rotation axes: collimator, gantry and couch. They are not intersecting at a point, but within a sphere. The radius of this sphere determines the isocenter accuracy.	No change in existing *IsoLock* procedure (§II.E).
MVD, kVD, kVS Positioning verification	Precision ruler: The positional accuracy of the imaging systems is verified.	Custom designed phantoms, automated EPID image acquisition, and a custom designed software application for image analysis was used to perform this test (§II.E.1).
MV Imaging	Las Vegas Phantom: Image quality tests for the MV and kV are verified to ensure they meet specifications.	
kV Imaging	Unfors system (RaySafe, Billdall, Sweden)	

Test	Tools: Testing methodology	
	Conventional AT	EPID-based AT
Jaw Parallelism	Graph Paper: Test is performed to ensure that jaws are parallel to the crosshairs.	EPID images acquired through the phantom were used to quantify the jaws positions and skewness with the help of the embedded steel-spheres (§II.E.2).
Coincidence of light field and x-ray field	Film: Correct alignment of the radiation field is always checked by the light field, and hence the coincidence of light field and x-ray field should be verified.	The embedded steel-spheres on the custom phantom provide a way to visually verify the light field and aid in analysis of the acquired EPID image (§II.E.2).
MLC Static Leaf Positioning Accuracy	Graph paper: Check the positional accuracy of the MLC leaf positioning.	EPID images acquired through the phantom were used to determine the positions of the MLC leaves (§II.E.2).
MLC Leaf Position Repeatability	Graph paper: Check the positional accuracy of the MLC leaf positioning after the MLCs have been cycled through different shapes.	This test is performed by acquiring an EPID image before and after MLC cycle without the phantom. Difference image is used to quantify the errors in leaves positions (§II.E.2).
Dosimetry verifications • Dose with MU • Dose with MU/min • Dose with Gantry	Ionization chamber with build-up cap and electrometer: The characteristics of the monitor unit device (ionization chamber that intercepts the treatment beam) are checked.	Open field EPID images acquired, in dosimetry calibration mode, for different test conditions were analyzed to verify the machine delivery accuracy (§II.E.3).
Energy and beam profile verification	Wellhoffer Buddleship: The energy of the photons and electrons is determined by measuring the central axis percent depth dose. The off-axis characteristics of clinical beams are measured by obtaining profiles.	PSM corrected open field EPID images are used to verify the beam energy, flatness and symmetry constancy via inline and crossline off-axis profiles (§II.E.4).

EPID based ATP phantoms

- Phantoms

(A) custom built phantom for photon beams; (B) phantom plate showing the steel plugs, CAX steel-spheres and resolution plug; (C) double wedge phantom used for AT of electron beams; (D) *IsoCal®* phantom used with the MPC

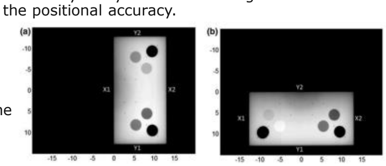


Mechanical test – Collimating system check

- Conventional approach -- Visual inspection of light field projected on a graph paper that is placed on the couch at isocenter distance.
  - Jaws parallelism
    Jaws driven to known positions and the light field is visually inspected to check their positions and that they are parallel with reference to the crosshairs.
  - MLC static leaf positioning accuracy and repeatability
    MLCs are shaped to different patterns and a visual inspection of the light field is performed to check their positional accuracy.

EPID based Jaws parallelism test

- Independent jaw locations with respect to steel-spheres embedded in the phantom are automatically analyzed on EPID images to test the skewness as well as the positional accuracy.
- Results: The skew over 20 cm for the X1 and Y2 jaws was 0.20° and 0.17°. no skew observed on the X2 and Y1 jaws.



EPID based MLC static positioning test

- Images were taken with standard MLC pattern from Vendor. The MLC leaf positions relative to the crosshairs are measured.
- Results1: The deviations 0.13±0.46 mm at 5 cm. 0.45±0.23 mm at 15 cm;
- Results2: Position deviation of 0.10 mm for A-side at 10 cm and 0.15 mm for B-side at 10 cm.

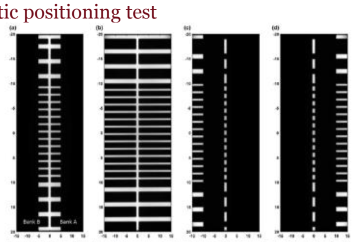


FIG. 5. EPID images obtained for verification of MLC positional accuracy. (a) Leaf position 5 cm (b) Leaf position 15 cm (c) Leaf position A-side 10 cm (d) Leaf position B-side 10 cm. All units are in cm. Note: Some MLC leaves are at the planned position, while others are 0.5 cm from central axis in these standard MLC patterns.

EPID based MLC repeatability test

- MLCs form a standard pattern before and after going through a sequence of different field shapes (diamond, inverse diamond, interdigitation, island, circular, etc.),known as auto-cycle.
- Difference were obtained to evaluate the repeatability.
- Results: deviations 0.16±0.20 mm

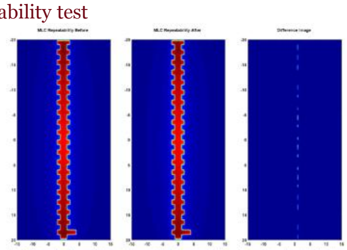


FIG. 6. EPID image showing the repeatability pattern before auto-cycle (left), after auto-cycle (middle), and difference between the two (right). All units are in cm. [Color figure can be viewed at wileyonlinelibrary.com]

EPID Based Relative Dosimetry Measurement

- Conventional approach: Securely suspending an ionization chamber (IC) with a build-up cap at a SDD of 100 cm, over the tip of the couch top.
- EPID based test: dosimetry images were acquired in dosimetry calibration mode by positioning the EPID panel at a SDD of 100 cm for a 10 x10 cm open field at different dose, dose rate, and gantry angle settings. The acquired EPID images were analyzed by obtaining the mean calibrated units (CU) from the central 11 x 11 pixel region.

TABLE I. Results for dose reproducibility.

		6 MV	15 MV
Dose	25 MU	−0.39 ± 0.42%	−0.26 ± 0.10%
	75 MU	0.25 ± 0.14%	0.17 ± 0.08%
Dose rate	100 MU/min	0.29 ± 0.04%	0.21 ± 0.10%
	600 MU/min	−0.33 ± 0.10%	−0.28 ± 0.07%
Gantry angle	90°	−0.01 ± 0.14%	−0.20 ± 0.07%
	270°	−0.01 ± 0.19%	−0.01 ± 0.08%

Beam energy and profile verification

- Beam energy, beam profile flatness and symmetry need to be verified.
- Conventional AT test for Varian: Wellhoffer Buddleship (measure PDD, BPs)

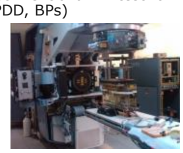


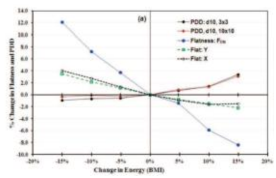
Image courtesy https://www.indeed.com/cmp/Varian-Medical-Systems/photos

Beam energy verification

- Do we have to use Buddleship?

Ionization chamber array (IC Profiler)

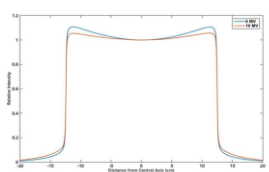
- Tuning beam energy by changing Bending Magnet Current then measure PDD and Beam profile.
- Conclusion: Flatness based metrics were found to be more sensitive to energy changes than PDD for photon beams.



Gao et al. Med. Phys. 40 (4), 2013

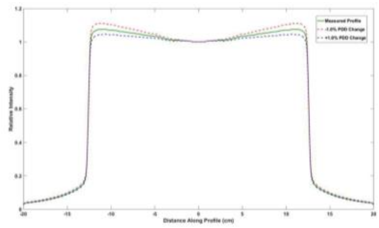
Beam energy verification

- Can we use EPID?
- Feasibility study: Can we correlate the beam energy change with the flatness change of beam profile?
- Approach: tune the beam energy (BMC) to make PDD change than take EPID images.
  - Photon 1% (10cm)
  - Electron 1mm (R50)



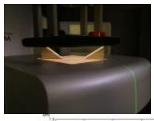
Beam energy verification

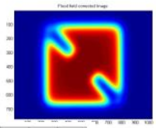
- Photon -- open field
- A 1% change in PDD (at 10 cm depth) resulted in a 2.5% change in flatness for a 6 MV.

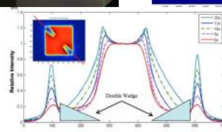


Beam energy verification

- Electron – double wedge phantom
- Beam profile under the wedge is used for analysis.



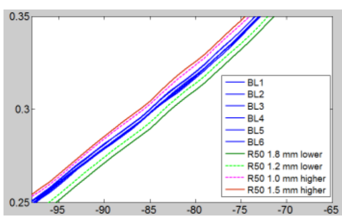




Beam energy verification

- Electron Results

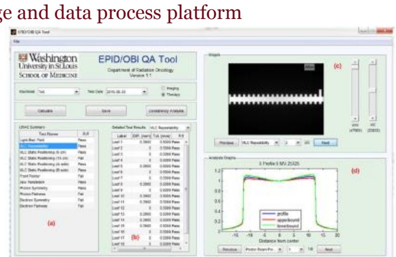
  Line shift was observed and the trend is correlated to the energy shift



Cai et al. Use of electronic portal imaging device (EPID) for quality assurance (QA) of electron beams on varian truebeam system. AAPM Poster Med Phys. 2015;42:3515.

Washington University School of Medicine in St. Louis
Department of Radiation Oncology
Division of Medical Physics

Image and data process platform



Washington University School of Medicine in St. Louis
Department of Radiation Oncology
Division of Medical Physics

EPID based auto-testing

Considerations

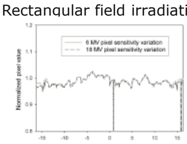
- EPID calibration
  - ➢ Mechanical calibration
    - ➢ Reasonable tolerance
    - ➢ Uncertainty analysis
  - ➢ Dosimetry calibration
    - ➢ Vender provided calibrations (dark field, flood field, dosimetry mode)
    - ➢ Pixel sensitivity Map

Washington University School of Medicine in St. Louis
Department of Radiation Oncology
Division of Medical Physics

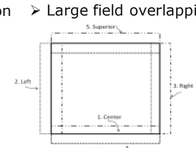
Pixel Sensitivity Map

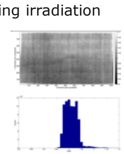
- PSM is used to normalize the variations in response of each pixel.

➢ Rectangular field irradiation ➢ Large field overlapping irradiation



Greer, Medical Physics, 32(12) 2005



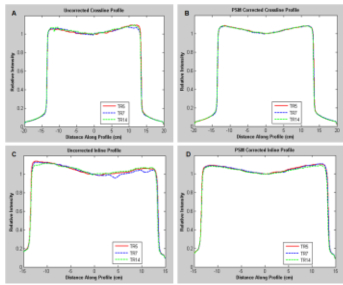


Sun, et al, Journal of Physics: Conference Series, vol. 573, p. 012041, 2015.
Cai et al., JACMP, under review

Washington University School of Medicine in St. Louis
Department of Radiation Oncology
Division of Medical Physics

Pixel Sensitivity Map

- Cross machine beam matching after PSM correction.



Other considerations

- EPID imaging artifacts
  - Ghosting effect
  - Saturation
  - Dead pixels
- Maintenance and regular QA for EPID

Conclusions

- Use of EPIDs can be extended to non-routine Linac QA.
- The developed process demonstrated that at least 25/45 (56%) of the AT tests which required customer demo can be streamlined and be performed using EPIDs.
- The preliminary data shows that EPID can be used for beam energy and profile verification.
- Imager calibration is critical and require regular QA and maintenance.

Acknowledgements

WashU
- Sasa Mutic
- Murty Goddu
- Baozhou Sun
- Hua Li
- Douglas Caruthers

U of Iowa
Sridhar Yaddanapudi

UCSD
- Todd Pawlicki
- Taylor Harry

Varian Medical System

SITEMAN CANCER CENTER

BARNES JEWISH Hospital BJC HealthCare | Washington University in St. Louis School of Medicine

Washington University in St. Louis
School of Medicine

Bin Cai
Campus Box 8224
4921 Park View Pl
St. Louis, MO 63110
(314) 687-7906

bcai@wustl.edu