The Current State of EPID-Based Linear Accelerator Quality Assurance

Timothy Ritter, PhD, DABR, FAAPM

Disclosures

Employed by the Veterans Health Administration

Faculty appointment with the University of Michigan (Adjunct Associate Professor)

Pending faculty appointment with Virginia Commonwealth University

Part of a Varian consortium investigating automated QA for TrueBeam accelerators

Purpose of this First Talk

Set the stage for the remaining presentations in this session

Present important historical and technological aspects of Electronic Portal Imaging Devices

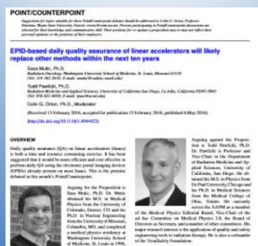
Review EPID properties applicable to machine QA

Introduce a few examples of how linac QA is currently being performed with EPIDs

Outline

- Historical Highlights
- aSi EPID Technology
- aSi EPID Performance
- Machine QA Examples

Required Reading


POINT/COUNTERPOINT

EPID-based daily quality assurance of linear accelerators will likely replace other methods within the next ten years

Sasa Mutic, Ph.D.

Todd Pawlicki, Ph.D.

Colin G. Orton, Ph.D., Moderator

OVERVIEW

Daily quality assurance (QA) on linear accelerators (linacs) is both a time and resource consuming exercise. It has been suggested that it would be more efficient and cost-effective to perform daily QA using the electronic portal imaging devices (EPIDs) already present on most linacs. This is the premise debated in this month's Point/Counterpoint.

Medical Physics
Volume 43 Issue 6,
p. 2691 – 2693, 2016.

Historical Highlights

For many years, film imaging was used for localization and verification of therapy setups

<u>Some limitations of film imaging</u>:

- Inconvenient to use
- Development takes several minutes
- Films must be stored
- Narrow dynamic range (latitude)
- Cannot be digitally processed
- Image quality and dose required

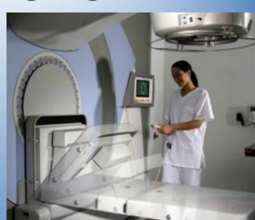
Historical Highlights

In response to the above concern, linac-mounted portal imaging devices were developed as early as the 1950s for imaging applications in radiotherapy.

Today's EPIDS represent 60 years of technological development!

Historical Highlights

www.varian.com, 07 Jul 2017



www.elekta.com, 07 Jul 2017

Historical Highlights

Challenges facing an electronic imaging approach:

- ✓ Space (where do you put it?)
- ✓ Mechanical positioning and accuracy
- ✓ Field of view
- ✓ Cost
- ✓ Image Quality
- ✓ Environment (radiation damage)

Historical Highlights

Two approaches to electronic portal imaging became widespread in the 1990s and early 2000s:

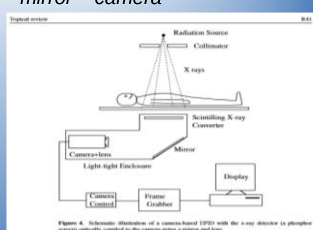
Phosphor – mirror – camera

Scanning matrix ionization chamber

Historical Highlights

Phosphor – mirror – camera

- The MV x-rays generate visible light in a metal/ phosphor plate assembly
- A mirror reflects the visible light into a camera

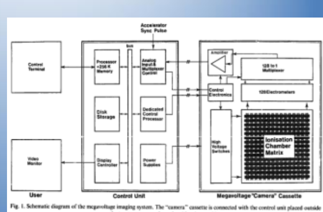


From Antonuk, *Electronic portal imaging devices: a review and historical perspective of contemporary technologies and research*, Physics in Medicine and Biology, 47, R31-R65, 2002.

Historical Highlights

Scanning matrix ionization chamber

- Two planes of electrodes separated by 0.8mm gap
- Gap is filled with an ionizing medium
- Metal (or other) plate covers the detector plane



From Van Herk and Meertens, *A matrix ionisation chamber imaging device for on-line patient setup verification during radiotherapy*, Radiotherapy and Oncology 11(4), 1988.

Historical Highlights

Multiple excellent references on the early history of electronic portal imaging

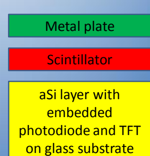
Antonuk LE, Electronic portal imaging devices: a review and historical perspective of contemporary technologies and research. Physics in Medicine and Biology 47, R31-R65, 2002.

Herman et al, Clinical use of electronic portal imaging: Report of AAPM Radiation Therapy Committee Task Group 58. Medical Physics 28 (5): 712-737, 2001.

aSi Technology

EPIDs today use amorphous silicon photodiode arrays that offer multiple advantages over the first generation technology described above.

Pixel of a modern aSi EPID



aSi Technology

Modern aSi EPIDs demonstrate high resolution (< 0.5mm), large detector size (approximately 40cm), mechanical precision of a few mm, and the ability to change the detector position laterally and longitudinally.

Modern aSi EPIDs display wide dynamic range and improved detective quantum efficiency over earlier EPIDs (more important for imaging than QA applications).

aSi Technology

It is essential to understand key operational characteristics of aSi EPIDs before implementing them for machine QA

aSi Technology

There are different methods of image acquisition, such as cine and integrated modes, that must be understood.

Example: Incomplete frame capture and memory overflow problems were reported under cine mode (Greer 2013).

Image lag, ghosting, loss of frames, and dose rate saturation have been observed. Understand these traits for your technology.

aSi Technology

From McCurdy, 2013:

"Image lag is due to trapped charge in the photodiode which, when read out in subsequent frames, results in the EPID signal being offset. Image ghosting refers to the change in individual pixel gains due to the trapped charge modifying the electric field strength in the photodiode…..However, these issues are primarily limited to short irradiation times (i.e. low number of monitor units) typically below those of routine clinical use, and also can be corrected for if desired [11, 12]."

McCurdy, *Dosimetry in radiotherapy using a-Si EPIDs: Systems, methods, and applications focusing on 3D patient dose estimation.* Proceedings of the 7th International Conference on 3D Radiation Dosimetry, 2013.

aSi Technology

The image (signal) captured by EPIDs is impacted by…

- Optical photons that are scattered within the scintillator
- x-ray photons scattered within the EPID
- x-ray photons backscattered from the mechanical arms holding the EPID

aSi Technology

aSi EPIDs require periodic calibration:

- ✓ “dark field” calibrations
- ✓ gain or “flood field” calibrations (assumes uniform field, equalizes pixel-to-pixel gains)
- ✓ bad pixel corrections

(there are additional corrections for portal dosimetry such as dosimetric calibrations, profile corrections, etc.)

aSi Performance

Let’s look at reported performance for some typical EPIDs:

- Field size effects
- Uniformity of response
- Dose and dose rate changes
- Energy dependence
- Mechanical stability

aSi Performance

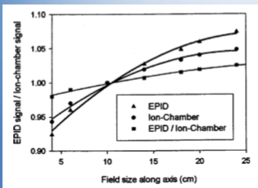


FIG. 3. Field size response of the EPID. The EPID signal change with field size is compared to the change in dose with field size measured with an ion chamber at 1.5 cm depth in a solid water phantom. The data are normalized to the 10×10 cm² field. Also shown is the ratio of the EPID readings to the ion-chamber readings.

Field size dependence

From Greer and Popescu, *Dosimetric properties of an amorphous silicon electronic portal imaging device for verification of dynamic IMRT*, Medical Physics 30 (7):1618-1627, 2003.

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aSi Performance

Effect of support arms/structure

Rowshanfarzad et al, *Measurement and modeling of the effect of support arm backscatter on dosimetry with a varian EPID*, Medical Physics 37 (5): 2269 – 2278, 2010.

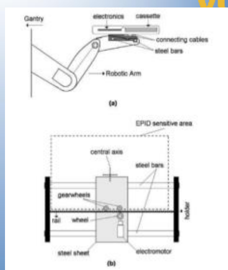

FIG. 1. Schematic illustration of EPID and support E-arm: (a) Lateral view and (b) back of the EPID, behind the rear housing and above the support arm.

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aSi Performance

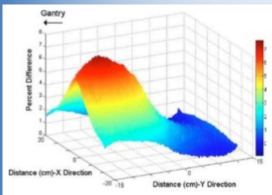

FIG. 2. Three dimensional illustration of the E-arm backscatter effect on EPID response for a 40×30 cm² image obtained by calculation of the percentage difference between measured *on* and *off arm* EPID response to a fixed dose.

Backscatter effect on uniformity

Rowshanfarzad et al, *Measurement and modeling of the effect of support arm backscatter on dosimetry with a Varian EPID*, Medical Physics 37 (5): 2269 – 2278, 2010.

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aSi Performance

Response Linearity

- aSI EPIDs display a *mostly* linear dose response
- There are often small non-linearities at low doses due to image lag, ghosting, frame drop, and other effects
- Very high dose rates (FFF beams) can be problematic

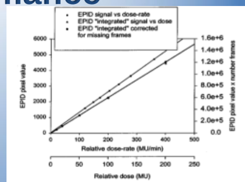


FIG. 2. Linearity of the EPID with dose rate and integrated dose. The dose rate to the EPID was varied by varying the source to detector distance. Ion-chamber readings were recorded at each EPID position in a mini-phantom to determine the relative dose rate. The relative dose rate is expressed in MU/min assuming a nominal output of 400 MU/min at 100 cm from the source. A measurement of integrated dose was obtained by multi-

From Greer and Popescu, *Dosimetric properties of an amorphous silicon electronic portal imaging device for verification of dynamic IMRT*, Medical Physics 30 (7):1618-1627, 2003.

aSi Performance

Some designs can accommodate the high dose rates of FFF beams

From Miri et al 2016:
…. The linearity of the EPID dose response was within 0.4% above 5 MU and ~ 1% above 2 MU. This linearity of response is a considerable improvement over previous reports for both Varian IAS3 and other vendor EPID systems which show under-response of 3%–5% for small MU.

From Miri et al, *EPID based dosimetry to verify IMRT planar dose distribution for the aS1200 EPID and FFF beams,* JACMP 17 (6):292-304, 2016.

aSi Performance

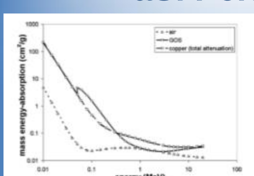


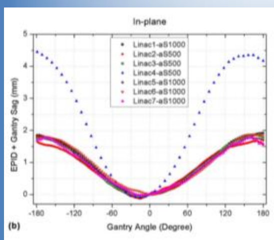
FIG. 3. Mass energy-absorption coefficients plotted as a function of photon energy for Gd_2O_2S (GOS) and air (Ref. 20). Air, the absorbing material of an ion chamber, has a reasonably uniform coefficient from 0.1 to 20 MeV. GOS, however, has a distinct rise below ~0.5 MeV. The total attenuation coefficient for Cu has also been plotted to indicate the relative proportion of photons of a given energy that would interact in a Cu plate placed upstream from the phosphor.

Energy dependence

High atomic number scintillators used in EPIDs over-respond to low energy photons

From Kirkby and Sloboda, *Consequences of the spectral response of an a-Si EPID and implications for dosimetric calibration,* Medical Physics 32(8):2649-2658, 2005.

aSi Performance



Mechanical Stability

- The EPID can flex, sag, or shift during gantry motion
- Gantry sag also comes into play

Image from Rowshanfarzad et al, *Detection and correction for EPID and gantry sag during arc delivery using cine EPID imaging*, Medical Physics 39 (2): 623–635, 2012.

aSi Performance

Mechanical Stability

Mans et al observed EPID flex up to 4mm…

- In order to perform quality assurance of VMAT plans, frames were aligned to the beam outlines from the plan
- Alignments were performed at 20 degree intervals along the arc, with corrections applied to adjacent gantry positions

From Mans A, Remeijer P, Olaciregui-Ruiz I, et al. 3D Dosimetric verification of volumetric-modulated arc therapy by portal dosimetry. Radiotherapy and Oncology 94(2):181-187, 2010.

aSi Performance

Above are representative results. Each design is unique.

Imaging and portal dosimetry needs have driven physicists to explore many of the properties of EPIDS.

Bottom line: EPID performance is well documented in the literature.

aSi Performance

Can machine QA be performed with EPIDS?
Of course, it has been done for years.

Limitations in EPID response and performance must be taken into account when developing methods.

QA Application Examples

Machine QA with EPIDS must consider factors such as:

- ✓ The impact of calibrations
- ✓ Changes in response over time
- ✓ Multiple scatter concerns
- ✓ Energy response effects
- ✓ Sag/flex
- ✓ The need for EPID QA

QA Application Examples

EPIDs are used for quality assurance testing of jaws and multi-leaf collimators

- ➢ Field size (jaws and MLCs)
- ➢ Radiation to light field (jaws and MLCs)
- ➢ Picket fence (MLC)

EPID-based verification of the MLC performance for dynamic IMRT and VMAT

Pejman Rowshanfarzad
School of Mathematical and Physical Sciences, University of Newcastle, Newcastle, NSW 2308, Australia

Mahsheed Sabet and Michael P. Barnes
Department of Radiation Oncology, Calvary Mater Newcastle Hospital, Newcastle, NSW 2310, Australia

Daryl J. O'Connor
School of Mathematical and Physical Sciences, University of Newcastle, Newcastle, NSW 2308, Australia

Peter B. Greer
Department of Radiation Oncology, Calvary Mater Newcastle Hospital, Newcastle, NSW 2310, Australia and School of Mathematical and Physical Sciences, University of Newcastle, Newcastle, NSW 2308, Australia

(Received 17 June 2012; revised 2 August 2012; accepted for publication 26 August 2012; published 24 September 2012)

Med. Phys. 39 (10), October 2012

Many implementations - both commercial and user-developed

QA Application Examples

- *Baker et al described precision MLC QA using an EPID, including the application of corrections, in 2005.*

Physics in Medicine & Biology

Use of an amorphous silicon electronic portal imaging device for multileaf collimator quality control and calibration

S J K Baker, G J Budgell and R I MacKay

Published 16 March 2005 • 2005 IOP Publishing Ltd

Physics in Medicine & Biology, Volume 50, Number 7

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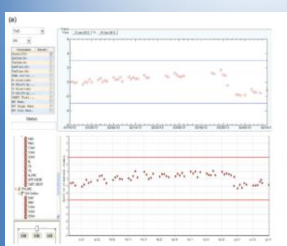
QA Application Examples



Output comparison

EPID vs daily QA device

From Sun, B. et al, Daily QA of linear accelerators using only EPID and OBI. Medical Physics 42 (10): 5584–5594, 2015.

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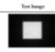
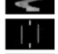
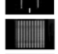
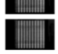
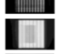
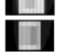
QA Application Examples

Eckhause et al developed an EPID-based machine test suite for TrueBeams:

- static and dynamic MLC position
- gantry angle and gantry sag
- collimator angle
- interleaf leakage
- jaw position

Eckhause et al, Automating linear accelerator quality assurance, Medical Physics 42 (10): 6074-6083, 2015.

TABLE I. Fields delivered as part of the test suite and the corresponding procedures tested.

Field description	Test Image	Procedure(s) tested
1. Jaw-defined field*		Gantry sag, collimator rotation, and jaw position
2. MLC defined static pattern*		Leaf positions
3. Interleaf static MLC pattern*		MLC transmission
4. Picket fence test—static gantry*		Leaf position (IMRT)
5. Picket fence test while gantry is rotating		Leaf position (IMRT) in ARC mode
6. Sliding window with variable gantry speed		Leaf position (IMRT) and variable travel speed
7. Sliding window with variable gantry speed and variable dose rate		Leaf position accuracy (IMRT), travel speed, and MU/angle

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QA Application Examples

Varian introduced Machine Performance Check as a supplement to standard QA

MV and kV images are used to assess…

- Isocenter size and location
- MV/KV/Tx isocenter coincidence
- Collimator rotation
- Gantry position
- Couch position
- MLC leaf position
- Jaw position
- Beam output, profiles, and central axis location

RADIATION ONCOLOGY

RESEARCH — Open Access

Evaluation of the Machine Performance Check application for TrueBeam Linac

Alessandro Clivio[1], Eugenio Vanetti[1], Steven Rose[2], Giorgia Nicolini[1], Maria F Belosi[1], Luca Cozzi[1], Christof Baltes[2] and Antonella Fogliata[3]

RADIATION PROTECTION & REGULATIONS — WILEY

Evaluation of the truebeam machine performance check (MPC) geometric checks for daily IGRT geometric accuracy quality assurance

Michael P Barnes[1,2,3] | Peter B Greer[1,3]

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QA Application Examples

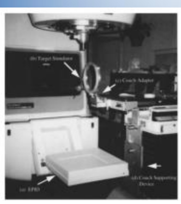

FIG. 1. The alignment setup with a retractable-arm electronic portal imaging device (a). The 3 mm tungsten ball was supported by a plastic rod mounted asymmetrically on one side of the target simulator (b). The target simulator assembly was attached to a couch adapter (c) which was supported by a special designed fixation device (d).

Numerous publications on Winston-Lutz style and other alignment tests

Here's one from 1997:

Medical Physics
The International Journal of Medical Physics Research and Practice

Explore this journal >

Verification of radiosurgery target point alignment with an electronic portal imaging device (EPID)

Lei Dong, Almon Shiu, Samuel Tung, Arthur Boyer

First published: February 1997 Full publication history

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QA Application Examples

What is "The Current State" of Machine QA with EPIDs?

1. Amorphous silicon EPID technology is well developed and understood from 20 years of commercial availability.
2. The literature has demonstrated a variety of machine QA applications, especially for mechanical and MLC checks.
3. Advanced applications are under development.
4. Some commercial solutions are available.

The next speakers in this session will dig into exciting details!

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Matt Schmidt Chris Shardlow

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