Key Patient QA Publications
Phantom-Based Patient-Specific QA

ArcCHECK® Accuracy Studies

A comparison of the gamma index analysis in various commercial IMRT/VMAT QA systems
M. Hussein, et al., Radiotherapy and Oncology 109 (2013) 370–376
• Study comparing ArcCHECK, PTW 729, Delta4, MatriXX, and Gafchromic Film.
• “Out of all the systems, ArcCHECK measurements exhibited the closest statistical agreement with the predicted gamma index...”

Optimizing the accuracy of a helical diode array dosimeter: A comprehensive calibration methodology coupled with a novel virtual inclinometer,
• Validation of ArcCHECK including: Field size dependence, angular dependence, dose rate dependence, and intrinsic relative sensitivity (array calibration) factors, along with Virtual Inclinometer.

“Robotic radiosurgery system patient-specific QA for extracranial treatments using the planar ion chamber array and the cylindrical diode array”
M. Lin, I. Veltchev, S. Koren, C. Ma, J. Li, Univ of Maryland School of Medicine, Fox Chase Cancer Center, JACMP 16 (4), (2015)
• Study of ArcCHECK versus MatriXX for small field CyberKnife treatments
• Specifically compares Angular Dependence, Detector Accuracy, and Sensitivity to various errors on both devices.
• Concludes:
  - Diodes are more accurate for small field measurements
  - ArcCHECK angular dependence is much lower than MatriXX, and therefore doesn’t require correction for CyberKnife treatments.
  - ArcCHECK used at 2%/2mm criteria is superior at detecting Gantry Angle errors, Sup/Inf misalignments, MU changes, and Random Errors. Says MatriXX is superior at Left/Right misalignment detection only.
  - “The maximum angular correction for a given beam is 8.2% for the MatriXX and 2.4% for the ArcCHECK system, respectively.”

“As seen in the profile comparison, the 4.5 mm wide ion chamber detectors of the MatriXX System causes a noticeable spatial averaging effect on the measured dose.”

*With 0.8 by 0.8 mm2 diodes, the output factors... agree better with the commissioning data.*

*The maximum angular correction for a given beam is 8.2% for the MatriXX and 2.4% for the ArcCHECK system, respectively.*
Commissioning Monte Carlo algorithm for robotic radiosurgery using cylindrical 3D-array with variable density inserts
Dechambre, et al., Liege University Hospital, Belgium, European Journal of Med Physics, 33 (152-158) (2017)

- Study showing the ArcCHECK with Multiplug allowed for comprehensive commissioning of Cyberknife Monte Carlo algorithm and is useful for patient specific QA for stereotactic body radiation therapy
- “Due to effective detector spacing of 5 to 7mm (depending on beam angle), the small active detector size (.8 x .8mm) of the diodes guarantees a correct dose measurement whenever irradiated by the beam”

Automated Planning and Delivery of Hippocampal Avoidance Whole-Brain Radiotherapy for Brain Metastases Using HyperArc Technology,
I Rusu*, et al. Loyola Univ Medical Center, Maywood, IL, WE-C1000-GePD-F7-5, AAPM 2019

- ArcCHECK successfully used to perform PSQA on HyperArc plans.

Filmless methods for quality assurance of Tomotherapy using ArcCHECK
Yang, et al., Hong Kong, Med. Phys., 44 (7-8) (Jan 2017)

- Study showing the ArcCHECK (AC) is also an excellent TG-148 Machine QA tool for TomoTherapy
- “Precise and efficient methods for measuring the gantry angle and speed, leaf open time, couch translation per gantry rotation, couch speed and uniformity, and constancy of longitudinal beam profile of TomoTherapy using ArcCHECK have been developed and proven to be accurate”
- “With its helical diode array, the AC is able to address some of the small field dosimetry challenges. Diode characteristics include quick response time, excellent spatial resolution, absence of external bias, micro-sized detector volume and high sensitivity”

EP-1533: Sensitivity of ArcCheck system to setup error using Perfect Pitch 6D couch
Sir HN RF Hospital, Radiation Oncology, Mumbai, India, ESTRO 2016

- Study demonstrating use of ArcCHECK and rotational error detection with 6DOF couch
  - “In this study, ArcCheck diode array showed high sensitivity to rotational setup errors. ArcCheck 3D diode array is capable of detecting a setup error in order of 1 mm/0.5.”
**ArcCHECK® Studies on the Varian Halcyon™ System**

**Clinical Evaluation of Lung SBRT for the Halcyon Platform and Dosimetric Comparison with the Truebeam STx and Millennium MLC Systems,**
- ArcCHECK used to perform PSQA on Lung SBRT plans from Halcyon v1.0 and v2.0.

**Optimized Volumetric Modulated Arc Therapy (VMAT) Technique for Left Sided Breast Cancer Comprehensive Radiation Therapy Via the Halcyon Delivery System,**
S Goddu, et al., Washington University School of Medicine, St. Louis, MO, TU-F115-GePD-F7-4, AAPM 2019
- ArcCHECK used to validate Halcyon breast plans.

**Plan Quality and Delivery Efficiency Comparison Between Halcyon 2.0 and Tomotherapy Hi-Art,**
W Feng, et al., St. Barnabas Medical Center, Livingston, NJ, PO-GePV-T-207, AAPM 2019
- ArcCHECK used to validate Tomotherapy vs. Halcyon delivery.

**Plan Quality Comparison for Cervical Carcinoma Treated with Halcyon and Trilogy Intensity Modulated Radiotherapy,**
C Li, et al., Department of Radiation Oncology Physics, Shandong Cancer Hospital Affiliated to Shandong University, Jinan, PO-GePV-P-89, AAPM 2019
- ArcCHECK used for Halcyon validation.

**Experience in commissioning The Halcyon linac,**
T Netherton, et al., University of Pennsylvania, Perelman Center for Advanced Medicine, Philadelphia, PA, Med. Phys., July 2019
- Validation of Halcyon beam models at two centers using ArcCHECK, Daily QA 3, IC PROFILER, EDGE Detector and other vendors’ devices.

**3DVH® Studies**

**VMAT QA: Measurement-guided 4D dose reconstruction on a patient,**
- Comprehensive explanation of the AC-PDP algorithm.
- Accuracy study with multiple ion chambers and film planes.

**Moving from gamma passing rates to patient DVH-based QA metrics in pretreatment dose QA,**
- Evaluation of 3D Gamma as a clinical metric versus 3D volumetric analysis.

**Evaluating IMRT and VMAT dose accuracy: Practical examples of failure to detect systematic errors when applying a commonly used metric and action levels,**
- Four separate hospitals submitted an article on errors they discovered using 3DVH but were missed by conventional planar Gamma analysis.

**Under-dose due to over-modulation:**
Despite a 3%/3mm passing rate of 93.9%, a large number of very narrow fields produced a 5.5% cold region across the target areas. Error was only obvious using 3D QA.
Why do 3D Patient-Specific QA?

Tolerance limits and methodologies for IMRT measurement based verification QA: Recommendations of AAPM Task Group No. 218
M Miften, et al., Med. Phys. 45 (4), April 2018
• Recommends 3D QA (such as ArcCHECK, 3DVH, or PerFRACTION) in order to cover the entire clinical treatment area

Using a Novel Dose QA Tool to Quantify the Impact of Systematic Errors Otherwise Undetected by Conventional QA Methods: Clinical Head and Neck Case Studies,
• “Although all per-beam planar IMRT QA had high Gamma passing rates...there were significant errors in some of the calculated clinical dose metrics”

Per-beam, planar IMRT QA passing rates do not predict clinically relevant patient dose errors,

PlanIQ™ Accuracy Studies

Utilization of Pinnacle Auto-planning and Sun Nuclear’s Plan IQ to Improve Efficiency,
Swanson, W., et al, University Hospitals, Seidman Cancer Center, Cleveland OH, AAMD 2019
• This study evaluated the ability of Plan IQ to generate custom OAR constraints per patient anatomy, document them, and improve plan quality
• Conclusion: “Pinnacle Auto-Planning combined with Plan IQ produced superior plans than manually planned or Auto-Planning with “generic” constraints on a faster timeline.” (saved an average of 3.5 hours per optimization)
PlanIQ™ Accuracy Studies cont.

Evaluation of auto planning in IMRT and VMAT for head and neck cancer,
Z Ouyang, Cleveland Clinic, Cleveland, OH, USA, J Appl Clin Med Phys 2019; 20:7:39–47
• "This auto planning tool is promising in reducing clinical workload and improving plan quality. DVH predictions with PlanIQ feasibility show good agreement with AP VMAT plans (dotted line plans)."
• "PTV dose coverage was similar or improved while the doses to critical structures were decreased beyond the desired dose limits."

A method for a priori estimation of best feasible DVH for organs-at-risk: Validation for head and neck VMAT planning,
• Accuracy and Clinical Efficacy Study on Feasibility: "A tool that allows a priori estimation of the best possible sparing (Feasibility DVH, or FDVH) of an organ at risk (OAR) in (tx) planning may help reduce plan quality variability by deriving patient-specific OAR goals prior to optimization."

Assessment of PlanIQ Feasibility DVH for head and neck treatment planning,
Fried, D. et al., Radiation Oncology Physics 2017
• Clinical study on Feasibility proving the following hypothesis: "There are limited tools to determine what is dosimetrically achievable and frequently the experience of the planner/physician is relied upon to make these determinations. PlanIQ software provides a tool that uses target and organ at risk (OAR) geometry to indicate the difficulty of achieving different points for organ dose–volume histograms (DVH)."

Variation in external beam treatment plan quality: An inter-institutional study of planners and planning systems,
B. Nelms, et al., Practical Radiation Oncology 2012
• "There is a large inter-planner variation in plan quality as defined by a quantitative PQM score that measures the ability of the planner to meet very specific plan objectives."

SunCHECK™ Patient Accuracy Studies

Can a commercially available EPID dosimetry system detect small daily patient setup errors for cranial IMRT/SRS?
Hsieh, et al., School of Veterinary Medicine, University of California Davis, Pract Radiat Oncol. 2017 Jul - Aug;7(4).
• Study showing PerFRACTION can detect setup errors down to 1mm for SRS, and 3mm for IMRT

Real Time dose computation; GPU-accelerated source modeling and superposition/convolution,
• "Real-time dose computation is feasible with the accuracy levels of the superposition/convolution algorithm,"

Towards real time radiation therapy: GPU accelerated superposition/convolution
Jacques, R., et al., John Hopkins University, Computer Methods and Programs in Biomedicine 98(3), 2010
• "Validation study of GPU accelerated superposition/convolution based dose engine with real-time performance."
Validation of a GPU-Based 3D dose calculator for modulated beams

- Validates the accuracy of DoseCHECK/ PerFRACTION's Dose Calculator (SDC)
- 6MV, 10FFF, and 15MV energies were analyzed using a set of IMRT and VMAT plans based on AAPM Practice Guideline 5a
- DoseCHECK/PerFRACTION 3D dose were compared with ion chamber, diode array, Pinnacle 3D dose, and MGD 3D dose

Validation of three-dimensional electronic portal imaging device-based PerFRACTION™ software for patient-specific quality assurance,

- Study on accuracy in heterogeneous environments and setup error detection.
- "With PerFRACTION, actual treatment quality could be determined in relation to machine, attachment, patient, and setup variations arising in practice. This may help direct adaptive replanning strategies to optimize therapeutic ratio."

Comparison of CT number calibration techniques for CBCT-based dose calculation

- Validated CBCT density override approach resulting in dose calculations that were consistent with those calculated on diagnostic-quality CT images.
- CBCT images of the lung, pelvis, and Head & Neck cases were studied.

Comparison of two different EPID-based solutions performing pretreatment quality assurance: 2D portal dosimetry versus 3D forward projection method,

- "3D PerFRACTION was able to detect all the delivered perturbations (induced errors). Defining clinical meaningful dose variations as 3% or greater, we can assert that Fraction 0 detected 100% of the errors"
- PerFRACTION found no False Positives; conversely, Varian's Portal Dosimetry(PDIP) had 13 False Positives, and 2 False Negatives (failed to detect real errors).
Sensitivity study of an automated system for daily patient QA using EPID exit dose images,

- Study of the Sensitivity of new PerFRACTION software to induce errors.
- States that PerFRACTION is "sensitive enough to detect small positional angular and dosimetric errors within 0.5mm 0.2 degrees and 0.2% respectively."

First Report of the Clinical use of a Commercial Automated System for Daily Patient QA using EPID Exit Images,
A. Olch, et al., University of Southern California and Children's Hospital Los Angeles, University of Southern California, University of Southern California and Children's Hospital, Advances in Radiation Oncology (2019) 1-7.

- "...the near total automation of the system provides the practical means to potentially acquire daily dosimetric QA information for every field every day for every patient."
- "This information fills an unmet QA need, making dosimetric QA an integral part of daily delivery of therapy."

Phantom-Less Patient-Specific QA
SunCHECK™ Patient - PerFRACTION™ Clinical Studies

In vivo dosimetry using CBCT and EPID device: analysis of sources of errors in VMAT treatments,
S. Bresciani. et al., Candiolo Cancer Institute - FPO- IRCCS, Candiolo TO, Italy, PV-0484, ESTRO 2019

- "Clinical findings: Dose failures occur mainly in air-tissue interfaces and in superficial regions, in fact the deviations greater than 5% were observed in lung patients (30%), partial breast irradiation plans (27%) and palliative treatments (20%)."
- "For the fractions that exceed 3% (dose difference), the errors are due to: setup (29%), patient anatomy (40%), setup + anatomy (27%) and bolus positioning (4%)."
- "Conclusion EPID-based IVD is a powerful method to catch and quantify delivery discrepancies during radiotherapy process."

1-year experience with automated transit in vivo dosimetry in a busy multicenter department,

- Study of all patients for 1 year at a hospital system that starts 5600 patients/year
- "Most common causes were patient positioning and anatomy changes such as weight loss (41%) and deviations in bladder or rectal filling (6%)."
- "Conclusion: A standardized transit dosimetry program using a decision tree was introduced in a busy department...After 6 months half of the observed deviations could be reduced, contributing to a wide acceptance level in our department."
A Multidisciplinary approach to Palliation - Rapid Access Targeted Personalised Radiotherapy Clinic,
A. Sharif, et al., GCUK, Medical Physics, Nottingham, United Kingdom, EP-1630, ESTRO 2019
- "PerFRACTION™3D – independent automated phantom-less end to end QA solution for all patient plans and fractions. A report is automatically compiled and accessed via the web user interface. A traffic light system efficiently flags any issues with the option of viewing more information if needed."
- "Conclusion Using Standardisation as a prerequisite, automation can be achieved. The automation allows production of consistently good plans and streamline of checks. The time saving can be utilised to support a Rapid Access Palliative clinic."

In vivo dosimetry with electronic portal imaging device in VMAT for prostate cancer,
S. Inui, et al., Osaka International Cancer Institute, Radiation Oncology, Osaka, Japan, EP-1747, ESTRO 2019
- Used PerFRACTION to study translational shifts and air cavities in Prostate patients
- "Conclusion This study suggests that EPID-based IVD is better for identifying inhomogeneity regions such as those with rectal gas than for detecting systematic setup errors in VMAT for prostate cancer patients."

Why Perform In Vivo QA?
AAPM Vision 20/20 Paper - "In vivo dosimetry in external beam radiotherapy,"
B. Mijnheer, et al., The University of Texas MD Anderson Cancer Center, International Atomic Energy Agency, University of Chicago Medical Center, Med. Phys. 40 (7), July 2013
- "It is the authors’ opinion that all treatments with curative intent should be verified through in vivo dose measurements in combination with pretreatment checks."

A quantification of the effectiveness of EPID dosimetry and software-based plan verification systems in detecting incidents in radiotherapy,
Bojechko C, et al., Department of Radiation Oncology, University of Washington, Med Phys 42(9), Sept 2015
- Study over 2.5 years of all failure modes related to mistreatments and near misses - 343 incidents rated "potentially severe" or "critical." Found that 74% of errors could be detected with the addition of First fraction In Vivo QA.
- "The most effective EPID-based dosimetry verification is in vivo measurements during the first fraction."

Catching errors with in vivo EPID dosimetry,
- 9 of the 17 would NOT have been detected by Pre-Treatment QA only.
- 7 of the 17 were patient anatomy changes & setup errors, only detectable via In Vivo QA
- "Furthermore, log file analysis is not completely independent, since it depends on the logging of data by the control system supplied by the equipment vendor, and would not detect, for instance, errors in the readout system itself."
Why is Independence Important?

Monitoring daily MLC positional errors using trajectory log files and EPID measurements for IMRT and VMAT Deliveries,
- Study method - One year of MLC picket fence data from 2 TrueBeams’ Trajectory log files vs. EPID images.
- “Over the duration of the study, multiple MLC positional errors were detected using the EPID based software but these same errors were not detected using the trajectory log files.”
- “In this study it was found that the trajectory logs did not detect leaf positional errors that were detected using an EPID.”

A clinically observed discrepancy between image-based and log-based MLC positions
- Study showing a clinical case in which real-time intra-treatment imaging identified a multileaf collimator (MLC) leaf to be consistently deviating from its programmed and logged position by >1 mm
- “It has been clinically observed the log-file derived leaf positions can differ from their actual position by >1mm, and therefore cannot be considered to be the actual leaf positions.”
- “This cautions against using…log files for MLC QA, patient QA, or patient dose verification.”
- “It seems apparent that real-time image-based QA may be a solution to this dilemma.”

Do Task Group External Beam QA Recommendations Guarantee Accurate Treatment Plan Dose Delivery?
A. Templeton, et al., Rush University Medical Center, Chicago, IL, Med. Phys. 42, 3395 (2015)
- Shows that TG-142 machine QA could be insufficient as a means to ensure that patient plans are delivered accurately.
- “Unacceptably large changes in dose delivered are possible… despite the machine passing routine QA.”
- “By following the minimum standards for machine QA, large dose errors (greater than 10%) may be produced.”
- “Conclusion: The cumulative effect of many small errors can, in worst case scenarios, produce large ones. This amalgam should be considered as part of the QA process.”