Patient QA
Recommended Publications
3DVH® Accuracy Studies

  • Non-coplanar reconstruction accuracy study.

“Validation of measurement-guided 3D VMAT dose reconstruction on a heterogeneous anthropomorphic phantom,” D. Opp et al., JACMP 14(4), (2013)
  • Accuracy study in heterogeneous phantom for lung VMAT plans with multiple ion chambers and film.
  • Proof of concept for Respiratory MotionSim accuracy.

  • Comprehensive explanation of the AC-PDP algorithm.
  • Accuracy study with multiple ion chambers and film planes.

  • Evaluation of 2D Gamma as a clinical metric versus 3D volumetric analysis.
  • Accuracy study of MC-PDP.

  • Evaluation of 3D Gamma as a clinical metric versus 3D volumetric analysis.
  • Accuracy study using a white box test.

3DVH® Clinical Studies

“Evaluating IMRT and VMAT dose accuracy: Practical examples of failure to detect systematic errors when applying a commonly used metric and action levels,” B. Nelms et al., Med. Phys. 40 (11), (2013)
  • Four separate hospitals submitted an article on errors they discovered using 3DVH but were missed by conventional planar Gamma analysis.

“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,” M. Chan et al., Memorial Sloan-Kettering Cancer Center, Technology in Cancer Research & Treatment 2013 June 24
  • Discovered both systematic and patient specific errors using 3DVH that were missed by Gamma QA. Used both EPIDose and film to verify all 3DVH discovered errors were true.
    "The authors found that the Gamma criterion of 3%/3mm (or 2%/3mm) was too lenient to detect systematic errors, especially when used in TPS commissioning."
    "Our study has confirmed the importance of advancing from phantom Gamma-based to patient DVH-based IMRT dose QA. Other researchers have come to this conclusion as well."
    "Most of these errors would not be discovered in routine QA. Each potential source of error found by 3DVH has been verified to be relevant and true." (Verified with film and EPIDose)

- Concludes that 5% DVH errors are missed with Gamma only analysis and that volumetric analysis is recommended for VMAT QA.

"It is recommended that the sole use of gamma index for Rapidarc QA plan evaluation could be insufficient and a methodology for evaluation of delivered dose to patient is required."


- Clinical study showing lung SBRT VMAT plans are less effected by organ motion than IMRT treatments.


- Clinical study showing method for planned dose perturbation (PDP) for TomoTherapy.
- Nineteen plans were analyzed with varying complexity and concluded that PDP is capable of volumetric dose reconstruction with acceptable accuracy.

**ArcCHECK® Accuracy Studies**

"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
  - Concludes ArcCHECK angular dependence is much lower than MatriXX, and therefore doesn’t require correction for CyberKnife treatments.
  - Concludes 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.

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

"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."

"The maximum angular correction for a given beam is 8.2% for the MatriXX and 2.4% for the ArcCHECK system, respectively."
**ArcCHECK® Accuracy Studies Continued**

“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..."
  
  "Delta4 was found to have the lowest concordance coefficient based on measurements, indicating lower agreement with the predicted gamma index passing rate..."

“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"
  
  "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"

- 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” V. Mhatre et al., Sir HN RF Hospital, Radiation Oncology, Mumbai, India, ESTRO 2016

- Study demonstrating use of ArcCHECK and rotational error detection with 6DOF couch

  Gamma analysis passing rates with 3%/3mm criteria were used to evaluate sensitivity of ArcCHECK to detect translation and rotation errors with the 6DOF Perfect Pitch 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.”


- Validates ArcCHECK for VMAT QA and Machine QA.

  “For the intentionally introduced systematic leaf positioning errors of −0.5 and +1 mm, the detected leaf positioning errors was −0.46 ± 0.14 and 1.02 ± 0.26 mm, respectively. This demonstrated the submillimeter sensitivity of the proposed method.”

- On a variable-gantry speed delivery, the Virtual Inclinometer showed “excellent agreement” and “accurate and high reproducibility of the Virtual Inclinometer”. In testing, it has a mean standard deviation of 0.03 seconds (<1 degree).

  “This method is efficient and an easy experimental setup. It is suitable for routine quality assurance of VMAT.”

  “…its cylindrical geometry and spiral pattern of diode distribution are also suitable for machine QA for VMAT”

  “There are also some studies using log files to perform VMAT QA. It is assumed that the actual delivery process is truly represented in the log files. The major disadvantage of this method is that Dynalog files need to be validated against an independent system.”

  “EPID was investigated for VMAT machine QA…..But as noted by the authors, that test contains all delivery parameters at once and does not allow easy distinction of the sources in case of problem occurrence.”
**ArcCHECK® Accuracy Studies Continued**

"Measurement comparison and Monte Carlo analysis for volumetric-modulated arc therapy (VMAT) delivery verification using the ArcCHECK dosimetry system," M. Lin et al., JACMP 14 (2), (2013)

- Validation study of ArcCHECK for use with Cyberknife and non-coplanar beams.
- Found non-coplanar delivery makes a negligible difference below 20 degrees, and <1.2% difference up to 40 degrees.

>"We can therefore conclude that the impact of angular dependency for noncoplanar delivery is negligible." *Inherent to the (ArcCHECK) system is an assumption that center (target) dose is supposed to agree with the planned one if both the entrance and the exit doses agree with the predicted values. This assumption is certainly true.*


- Multi-hospital study to validate that FFF delivery was accurate with ArcCHECK, Delta4, and MatriXX.
- States that a "device as MatriXX could not be the optimal choice" when high resolution is needed for small or highly-modulated fields.


- Validates ArcCHECK: Field size dependence, angular dependence, dose rate dependence, and intrinsic relative sensitivity (array calibration) factors, along with Virtual Inclinometer.

"Performance of the ArcCHECK-MRTM QA System in a transverse 1.5 T magnetic field," A. Houweling et al., Tech note (2014)

- Validates ArcCHECK-MR for the MR-linac: No significant differences between the performance of the MR-linac and the clinical linac were observed.

>"The short term reproducibility, dose linearity, dose rate dependence, field size dependence, dose per pulse dependence and inter-diode variation of the ArcCHECK-MR diodes were not influenced by the presence of a 1.5 T magnetic field. Therefore, the ArcCHECK-MR can be used for QA of patient plans in the MR-linac*"
**ArcCHECK® Clinical Studies**

"Image-Guided Stereotactic Radiotherapy using the ArcCHECK Phantom," O. Sauer, C. Groh, University of Würzburg, Germany, AAPM Poster 2013

- Validation of ArcCHECK as a fast end-to-end test for SRS.
  "The implemented test (ArcCHECK) is capable of quantifying the agreement between lasers and kV isocenter with discrepancies in the sub-mm range."
  "... pass rate of the gamma-criterion were well correlated to set-up errors"


- Evaluated iPlan's PBC and MC algorithms for SRS/SBRT plans using ArcCHECK.
- ArcCHECK showed very good agreement on all Monte Carlo plans on a variety of SBRT body sites, with or without the plug.

"Patient-Specific Quality Assurance for the delivery of 60Co Intensity Modulated Radiation Therapy Subject to a .35-T Lateral Magnetic Field," H. Harold Li et al., International Journal of Radiation Oncology Biology/Physics, (2014)

- Examines the use of ArcCHECK-MR as part of a patient-specific intensity modulated radiation therapy quality assurance (QA) program for ViewRay.
- AC-MR measurements indicated the mean SD passing rate using 3% relative/3 mm gamma criteria was 98.9%.

**PlanIQ™ Clinical Studies**

"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."


  "This study suggests that peer review in radiation oncology is common and leads to changes in management in a meaningful fraction of cases. There is much variation in the manner of conducting, and reported utility of, peer review"

"Methods, software and datasets to verify DVH calculations against analytical values: Twenty years late(r)" B. Nelms, et al., Med Phys 42 4435, 2015

  "Custom analysis software was developed to study the important metrics of DVH accuracy. PlanIQTM exhibits fewer deviations from the ideal (DVH) values."
Patient vs. Phantom Geometry Studies


• 2D Planar Gamma passing rates shown to not correlate with clinically relevant errors.


• 3D and 3D volumetric Gamma passing rates still do not correlate well with clinical errors.
**EPID vs. Log File Studies**


- Study method: One year of 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 created during the delivery of a picket fence test did not detect leaf positional errors that were detected using an EPID.”

  “In this study it was found that the trajectory logs created during the delivery of a picket fence test did not detect leaf positional errors that were detected using an EPID.”

**A clinically observed discrepancy between image-based and log-based MLC positions”**

B. Neal et al., Med Phys. 43(2933), (2016)

- 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.”
Measurement vs. Calculation Studies

"Catching errors with in vivo EPID dosimetry," A. Mans et al., Department of Radiation Oncology, The Netherlands Cancer

- Detected 17 treatment errors out of 4337 treatments using an EPID based per fraction QA approach.

<table>
<thead>
<tr>
<th>(b) Error type</th>
<th>No. of errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient anatomy</td>
<td>7</td>
</tr>
<tr>
<td>Plan transfer</td>
<td>4</td>
</tr>
<tr>
<td>Suboptimally tuned TPS parameter</td>
<td>2</td>
</tr>
<tr>
<td>Accidental plan modification</td>
<td>2</td>
</tr>
<tr>
<td>Failed delivery</td>
<td>1</td>
</tr>
<tr>
<td>Dosimetrically undeliverable plan</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>17</td>
</tr>
</tbody>
</table>

- 9 of the 17 would NOT have been detected by Pre-Treatment QA only.
- 7 of the 17 were attributable to patient changes/setup (the largest category of error), which a log-file solution alone will never be able to detect because it ignores the patient.
- Patient changes detected - weight loss, setup error, obstructions from table arms or immobilization devices, tumor or internal anatomy changes (postoperative cavity drainage, atelectasis shrinkage, etc.).
- 4 of the 17 were plan transfer issues – some with drastic errors resulting from MLC/Jaw erroneous syncing.

"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."

![Image of gamma evaluations](image-url)

**FIG. 2.** γ-evaluations of (a) the first (malformed plan) and (b) the second (corrected plan) fractions in a plane parallel to the EPID, intersecting the isocenter. The white “+” indicates the isocenter.
PerFRACTION™ Accuracy Studies

"Can a commercially available EPID dosimetry system detect small daily patient setup errors for cranial IMRT/SRS?"
Hsieh et al., Pro Journal (2016)

- Study showing PerFRACTION can detect setup errors down to 1mm for SRS, and 3mm for IMRT
  
  "PerFRACTION 2D mode successfully detected setup errors outside of tolerance for IMRT (3mm DTA) and SRS (1mm DTA) when an appropriate analysis metric and pass/fail criteria was implemented."

  Provides guidance on which metrics to use for analysis. "When we removed the masking effect of the DTA by using percent difference for data analysis, per-field 2D EPID dosimetry was indeed capable of flagging the fields for which the dosimetric changes introduced by the shifts were largest."

AAPM Vision 20/20 Paper - “In vivo dosimetry in external beam radiotherapy” B. Mijnheer, S. Beddar, J. Izewska, C. Reft, Department of Radiation Oncology, The Netherlands Cancer Institute-Antoni van Leeuwenhoek Hospital, Amsterdam 1066 CX, The Netherlands, Department of Radiation Physics, The University of Texas MD Anderson Cancer Center, Houston, Texas 77030, Division of Human Health, International Atomic Energy Agency, Vienna 1400, Austria, Department of Radiation and Cellular Oncology, University of Chicago Medical Center, Chicago, Illinois 60637, 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."

  "Devices for the in vivo verification of the photon beam fluence exiting the linac by means of an array detector system positioned at the entrance side of the patient are also available. However, these devices do not provide information on the patient-specific contribution to the dose distribution, and will therefore not be considered as an in vivo dosimetry system..."

  "..there are looming regulatory compliance issues that may necessitate patient dosimetry17,18, and national recommendations3,19,20 for in vivo dose measurement during patient treatment."

  "Italy’s commissioned national study results - "The results of 480 tests showed errors exceeding the 5% tolerance level in 10% of the measurements, which were due to incorrect setup, the presence of an attenuator in the beam, or patient morphological changes."

"Real Time dose computation; GPU-accelerated source modeling and superposition/convolution" Jacques, R. et al., John Hopkins University, Medical Phys 38(1), Jan 2011

  "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."
PerFRACTION™ Accuracy Studies Continued


- States TG-142 machine QA could be insufficient as a means to ensure that patient IMRT/VMAT plans are delivered accurately.
- Method – Two errant simulation treatment machines were designed in Varian's Eclipse TPS. Error magnitudes remained within TG-142 testing limits.

“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.”


- Study showing examining sensitivity and specificity of EPID and PerFRACTION software

- Errors were induced in dose, patient AP shift, MLC positions, and anatomical variations (with 2cm bolus on phantom) to evaluate sensitivity and specificity of EPID with PerFRACTION for in vivo dosimetric and geometric measurements of VMAT treatments.

- Based on sensitivity and specificity study the authors conclude: “EPID device and PF software can be confidently used in clinical routine to detect dosimetric, geometrical and anatomical discrepancies.”

- Study of the Sensitivity of new PerFRACTION software to induce errors. Excellent sensitivity found – author states that PerFRACTION is, “sensitive enough to detect small positional angular and dosimetric errors within 0.5mm 0.2 degrees and 0.2% respectively.”


- Initial experience with PerFRACTION – 96% of fields passed at 3%/3mm criteria – 84% of fields passed at 1mm DTA.


- Discusses initial experience with PerFRACTION, including its detection of patient setup, deliver, and anatomy changes. This study was performed with very stringent gamma criteria (2%/1mm) in order to review as many cases as possible. Interesting finding – pass rates were higher for IMRT/VMAT plans than for Conventional fields, indicating patient setup may be an issue.

“A quantification of the effectiveness of EPID dosimetry and software-based plan verification systems in detecting incidents in radiotherapy” C. Bojechko, M. Phillips, A. Kalet, E.C. Ford, Department of Radiation Oncology, University of Washington, Med Phys 42(9), Sept 2015

- Pre-Tx EPID dosimetry detected 6% of errors (physics calculation errors, treatment machine error, and corrupted plans) – all modes with low number of occurrences
- First Fraction in vivo QA detected 74% of all failures – incidents with the highest occurrence (patient setup, CT dataset errors)

“The most effective EPID-based dosimetry verification is in vivo measurements during the first fraction”

- All Fraction in vivo QA added the ability to detect other common errors (movement on the table, treatment machine error, and setup errors)

“In vivo all fraction dosimetry gives an added benefit to 20% of events”
**PerFRACTION™ Accuracy Studies Continued**

**“Validation of a GPU-Based 3D dose calculator for modulated beams”** Ahmed et al., USF, Moffitt Cancer Center, Sun Nuclear Corp., J Appl Clin Med Phys (2017)

- Study validating the accuracy of the Sun Nuclear Dose Calculator (SDC)

  Three photon energies were examined: 6, 15 MV, and 10 MV FFF using a set of IMRT and VMAT plans based on four of the five AAPM Practice Guideline 5a

  Comparisons with the ion chamber, diode array measurements, and measurement guided 3D dose reconstruction for challenging datasets reveal the accuracy level expected in routine patient-specific testing [≥ 95% gamma(3%/2 mm) passing rates]

  Comparison with Pinnacle TPS showed similar agreement

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**“Comparison of CT number calibration techniques for CBCT-based dose calculation”** Dunlop et al., Royal Marsden Hospital, UK, Strahlenther Onkol, 191: 970-978 (2015)

- Study comparing and validating various computed tomography (CT) number calibration techniques with respect to cone beam CT (CBCT) dose calculation accuracy

  One of the methods presented is a density override approach where CBCT voxels are binned into six density levels (same method used in PerFRACTION)

  The RS auto density override approach was validated, resulting in dose calculations that were consistent with those calculated on diagnostic-quality CT images, for CBCT images acquired of the lung, for patients receiving pelvic RT in cases without excess adipose tissue, and for H&N cases.
Study investigating the feasibility and accuracy of dose calculation in cone beam CT (CBCT) data sets.

“The generation of three HU-D tables specific for the anatomical regions pelvis, thorax and head and specific for the corresponding CBCT image acquisition parameters resulted in accurate dose calculation in CBCT images.”

“Once these HU-D tables are created, direct dose calculation on CBCT datasets is possible without the need of a reference CT images for pixel value calibration.”