SunCHECK™ Patient Accuracy & Sensitivity Studies

Assessment of a commercial EPID dosimetry system to detect radiotherapy treatment errors

P. Doolan, et al, German Oncology Center, Limassol, Cyprus, Biomed. Phys. Eng. Express 7 (2021) 047001

- Purpose: Studied Sensitivity of PerFRACTION Transit Dosimetry on Elekta Linacs
- Introduced known errors in: Output, Field Size, Collimator Rotation, MLCs in groups, Single MLC, EPID Misalignment, Patient Misalignment, and Patient Weight Loss

Table 1. Table of results for radiation beam errors. The magnitude of induced error is listed, together with the dose difference (DD) or distance-to-agreement (DTA) tolerance required to obtain an acceptable passing rate. For a given test, the sensitivity is the largest of these values, which is highlighted with a **bold and underlined** typeface.

Test	Induced error	Lowest DD [%] or DTA [mm] with acceptable passing rate	PerFRACTION sensitivity
	+0.5%, −0.5%	0.8%, 0.7%	**0.3%**
Machine output	+1.0%, −1.0%	1.2%, 1.0%	0.2%
	+1.5%, −1.5%	1.6%, 1.5%	0.1%
	+1 mm, −1 mm	1.1 mm, 1.2 mm	0.2 mm
Field size	+2 mm, −2 mm	2.2 mm, 2.4 mm	**0.4 mm**
	+3 mm, −3 mm	3.4 mm, 3.4 mm	0.4 mm
	+1°, −1°, (0.9 mm)	0.8 mm, 0.8 mm	0.1° (0.1 mm)
Collimator rotation	+2°, −2°, (1.7 mm)	1.5 mm, 1.5 mm	0.2° (0.2 mm)
	+3°, −3° (2.5 mm)	2.2 mm, 2.2 mm	**0.3°** (0.3 mm)
	+1 mm, −1 mm	1.0 mm, 1.0 mm	0.0 mm
MLC group	+2 mm, −2 mm	2.0 mm, 2.1 mm	0.1 mm
	+3 mm, −3 mm	2.9 mm, 2.9 mm	**0.1 mm**
	+1 mm, −1 mm	0.5 mm, 0.9 mm	0.4 mm
Single MLC (6X)	+2 mm, −2 mm	1.0 mm, 1.9 mm	1.0 mm
	+3 mm, −3 mm	1.9 mm, 3.6 mm	**1.1 mm**
	1.6 mm	1.5 mm	0.1 mm
EPID misalignment (GT)	3.8 mm	3.8 mm	0.0 mm
	6.3 mm	6.0 mm	**0.3 mm**
	1.9 mm	2.0 mm	0.1 mm
EPID misalignment (AB)	3.8 mm	3.6 mm	0.2 mm
	6.3 mm	6.1 mm	0.2 mm

Abbreviations: DD = dose difference; DTA = distance-to-agreement.

Sensitivity study of an automated system for daily patient QA using EPID exit dose images

A. Zhuang, A. Olch, Department of Radiation Oncology, University of Southern California, Children's Hospital Los Angeles, J. Appl. Clin. Med. Phys. 2018: 1-11.

- 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."*

Table 2 Induced errors, DD, and/or DTA tolerance used, PerFRACTION-calculated Gamma passing rates, and the sensitivity of PerFRACTION.

Tested items	Induced errors	DD and/or DTA tolerance, or Gamma passing rates	Sensitivity of PerFRACTION
Jaw position	1.5 mm	1.3 mm	0.2 mm
MLC position	1.5 mm	1.1 mm	0.4 mm
Linac output	0.5%, 1.0%, 1.5%	0.5%, 1.2% and 1.6%	0.2%
Collimator rotation	1, 2 and 3°	0.7, 1.7 and 2.5°*	0.5°
Couch shift	1.5 mm	1.7 mm	0.2 mm

Can a commercially available EPID dosimetry system detect small daily patient setup errors for cranial IMRT/SRS?

E. Hsieh, et al., University of California, Davis, Davis, CA, U.S., 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

R. Jacques, et al., Johns Hopkins University, Boston, MA, U.S., Medical Phys 38(1), Jan 2011

- *“Real-time dose computation is feasible with the accuracy levels of the superposition/convolution algorithm”*

Validation of a GPU-Based 3D dose calculator for modulated beams

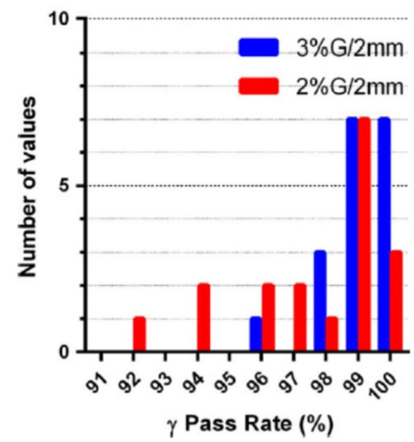
S. Ahmed, et al., University of South Florida, Tampa, FL, U.S., J Appl Clin Med Phys. 2017 May; 18(3):73-82

- 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

SDC vs. Ion Chamber

The calculated point doses are compared to the ion chamber measurements in Table 2. The primary TPS data are also presented for completeness. The SDC exhibits 0.2% average deviation from the ion chamber, well within the 1.5% recommended by TG-244 for the primary TPS in the high dose low gradient area.

				6 MV		10 FFF		15 MV	
TG-244 Patient/Test	Phantom	Point	Plan	SDC - IC (%)	Pinn. - IC (%)	SDC - IC (%)	Pinn. - IC (%)	SDC - IC (%)	Pinn. - IC (%)
ABDOMEN	PW Cube	Cube center	VMAT	0.6	1.0	0.3	0.6	0.8	0.8
			IMRT	0.1	-0.3	-0.1	-0.3	-0.05	-0.1
Head & Neck	PW Cube	Cube center	VMAT	-0.9	1.0	0.4	1.0	-0.3	0.6
			WFIMRT	-0.4	1.2	0.9	1.1	-0.8	0.6
ANAL	PW Cube	Cube center	VMAT	-2.0	1.4	-0.6	-1.6	-0.3	0.9
			WFIMRT	-1.1	2.0	0.01	1.0	-1.3	1.4
LUNG	CIRS Thorax	Target	VMAT	2.6	3.1	1.1	0.9	4.0	1.4
			WFIMRT	1.9	2.1	1.8	1.4	2.8	1.2
		"Mediastinum"	VMAT	1.3	2.5	-0.6	-2.0	-1.5	-2.8
			WFIMRT	0.3	0.8	-1.0	-4.0	-1.2	-5.4
			Average	*0.2*	*1.5*	*0.2*	*-0.2*	*0.2*	*-0.1*
			St. Dev.	*1.4*	*1.0*	*0.9*	*1.8*	*1.8*	*2.2*



*White Paper: DoseCHECK™ & PerFRACTION™ On the Accuracy of the SNC Dose Calculator Algorithm

Assessment of three software systems for the independent calculation of Eclipse HyperArc SRS plans

J. Calvo-Ortega, Hospital Vall D'hebron, Barcelona, Spain, ESTRO 2021, PO-1841

- *"Purpose or Objective: To perform independent dosimetric check of Eclipse HyperArc (HA) SRS plans by using three different software, in the context of patient-specific quality assurance (PSQA)."*
- *"Conclusion: Both DoseCHECK and PRIMO...agree with Eclipse HyperArc calculations for a TrueBeam, with no need for the user to fine-tune the calculation parameters. The Mobius 3D default model, however, would need tuning to match HyperArc dose distributions."*

	ECLIPSE vs Dosecheck		ECLIPSE vs M3D		ECLIPSE vs PRIMO	
Criteria	mean (SD)	AL-TG119	mean (SD)	AL-TG119	mean (SD)	AL-TG119
3% (G) 1 mm	99.7 (1.2)	97.4	94.3 (13.8)	67.2	97.6 (9.8)	78.5
5% (G) 1 mm	100.0 (0.1)	99.8	97.7 (11.4)	75.3	99.6 (2.5)	94.7
2% (G) 2 mm	99.9 (0.6)	98.7	98.5 (5.9)	87.0	99.0 (2.1)	94.9

A hybrid volumetric dose verification method for single isocenter multiple target cranial SRS

S. Ahmed, et al., Moffitt Cancer Center, Tampa, FL, U.S., Med Phys 2018; Vol 19, Iss 5:1–8

- PerFRACTION calculations for single target, Multi-Met cases were compared to Pinnacle calculations, 3D PDP calculations, ion chamber and film measurements.
- *"Results: Excellent agreement is observed for PF, with the lowest passing rate of 96.1%."*

Table 1: Results for the gamma comparison between PerFraction reconstructed dose and EBT-XD film measurements .

Plan	Plane	PerFRACTION vs. Film	
		3%/1mm	2%/2mm
T3	Oblique 45°	100	100
	Oblique 135°	99.9	99.93
PT3	Oblique 45°	100	100
	Oblique 135°	100	100
PT5	Coronal	99.4	99.1
	Oblique 45°	99.7	99.6
	Oblique 135°	97.3	95.8

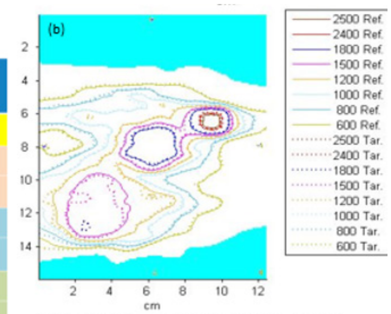


Figure 2: 2%/2mm γ map (a) and isodose overlay (b) for the PT5 oblique (135°).

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

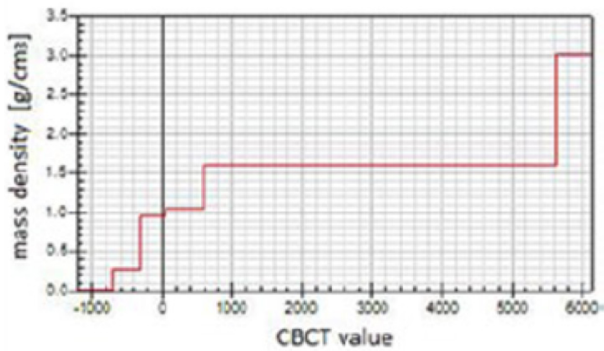
Sait A, et al., Cancer Center Eastern Caribbean, St. John's, Antigua and Barbuda, J Med Phys 2019;44:16-20

- Study on accuracy in heterogenious 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

Dunlop, et al., Royal Marsden Hospital, UK, Strahlenther Onkol, 191: 970-978 (2015)

- 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

S. Bresciani, et al., Candiolo Cancer Institute, Italy, Physica Medica 52 (2018) 65–71

- *"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).

		# FN	#TP	# TN	#FP	Sensibility	Specificity
PDIP (%GP>95%)	local 3%/3mm %GP	2	6	15	13	0.8	0.5
	global3%/3mm %GP	2	6	16	11	0.8	0.6
PerFRACTION (ΔDE%=3%)	DVH point doses	1	5	25	0	0.9	1

SunCHECK™ Patient for the Varian Medical Systems® Halcyon™ System

Validation and clinical Implementation of Sun Nuclear DoseCHECK and PerFRACTION for Varian Halcyon

E. Almond, et al, Queen's Hospital - Barking Havering and Redbridge Hospitals NHS Trust, Radiotherapy, UK, PO-1398, ESTRO 2020

- Summary – Discusses importance of independent algorithm and beam models
- "Purpose or Objective - *In the UK a Radiotherapy Provider should ensure that an independent dose recalculation is carried out. This recalculation must be independent of the planning computer"*
- *"Conclusion: DoseCHECK and PerFRACTION have shown good dose distribution agreement with Eclipse TPS. The result shows that DoseCHECK and PerFRACTION are both viable systems for independent dose calculations for patients being treated on the Halcyon platform in our clinic."*

SunCHECK™ Patient – PlanCHECK™ Clinical Studies

Automation of DVH constraint checks and physics quality control improves patient safety

N. Jensen, Rigshospitalet Oncology, Copenhagen, Denmark, ESTRO 2021, PO-1709

- Retrospectively used PlanCHECK to evaluate 47 breast cancer treatment plans
- *"Results: In the 47 breast cancer plans, retrospectively subjected to automated DVH check, 10 undocumented dose constraint violations were found, varying between 0.1 Gy and 14.5 Gy above clinical constraint."*
- *"Conclusion: We have shown that automating the physics QCR using a method demanding minimum time and programing skills improves patient safety compared to manual QCR by experienced medical physicists."*

Phantom-Less Patient-Specific QA

SunCHECK™ Patient - PerFRACTION™ In-Vivo Clinical Studies

Evaluation of automated pre-treatment and transit in-vivo dosimetry in radiotherapy using empirically determined parameters

E. Bossuyt, et al, Iridium Netwerk, Radiation Oncology Department, Belgium, Physics and Imaging in Radiation Oncology 16 (2020) 113–129

- Summary: A "how to" guide for in-vivo QA
- *Methods: "This study presents clinical results for more than 3000 patients, for EPID-based pre-treatment and in-vivo transit dosimetry. Analysis with an empirically determined set of parameters shows a wide variety of detected errors and deviations."*
- *Results: "Examples of a wide variety of detected errors and deviations, together with the appropriate corrective actions, are illustrated... Several of the discovered errors would have led to a dose difference of the total treatment of more than 5% if uncorrected."*
- *Conclusion: "[An] automated pre-treatment and in-vivo transit dosimetry system has been clinically implemented for all patients, efficiently revealing a wide variety of deviations using an empirically determined set of parameters for gamma analysis. Results show its potential to serve as a basis for adaptive planning."*

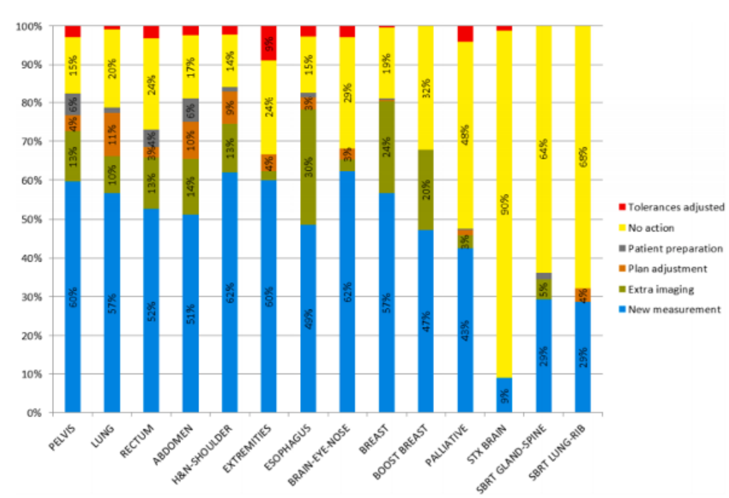


Fig. 4. Analysis of the actions for failed fractions in the second analysis classified per treatment site and/or technique: taking a new measurement; adding extra pre-treatment imaging; plan adjustment; taking measures regarding patient preparation (e.g. bladder and rectum protocol); taking no action; adjusting used tolerances.

Table 1
Summary of empirically determined parameters for gamma analysis of in-vivo transit dosimetry results.

	Normalization (Local/ Global)	Dose Difference Tolerance (%)	Distance Tolerance (mm)	Low Dose Threshold (%)	Passing Tolerance Level (%)
Breast	Local	7	6	20	90
Whole Brain RadioTherapy	Local	7	3	20	90
Palliative treatments	Local	7	5	20	93
H&N and Brain	Global	3	3	20	95
Rectum	Global	5	5	20	93
Other treatment sites with mask	Global	5	3	20	95
Other treatment sites without mask (including lung, pelvis, abdomen,…)	Global	5	5	20	95
Stereotactic 1 mm	Local	10	1	20	95
Stereotactic 2 mm	Local	10	2	20	95
Stereotactic 3 mm	Local	10	3	20	95

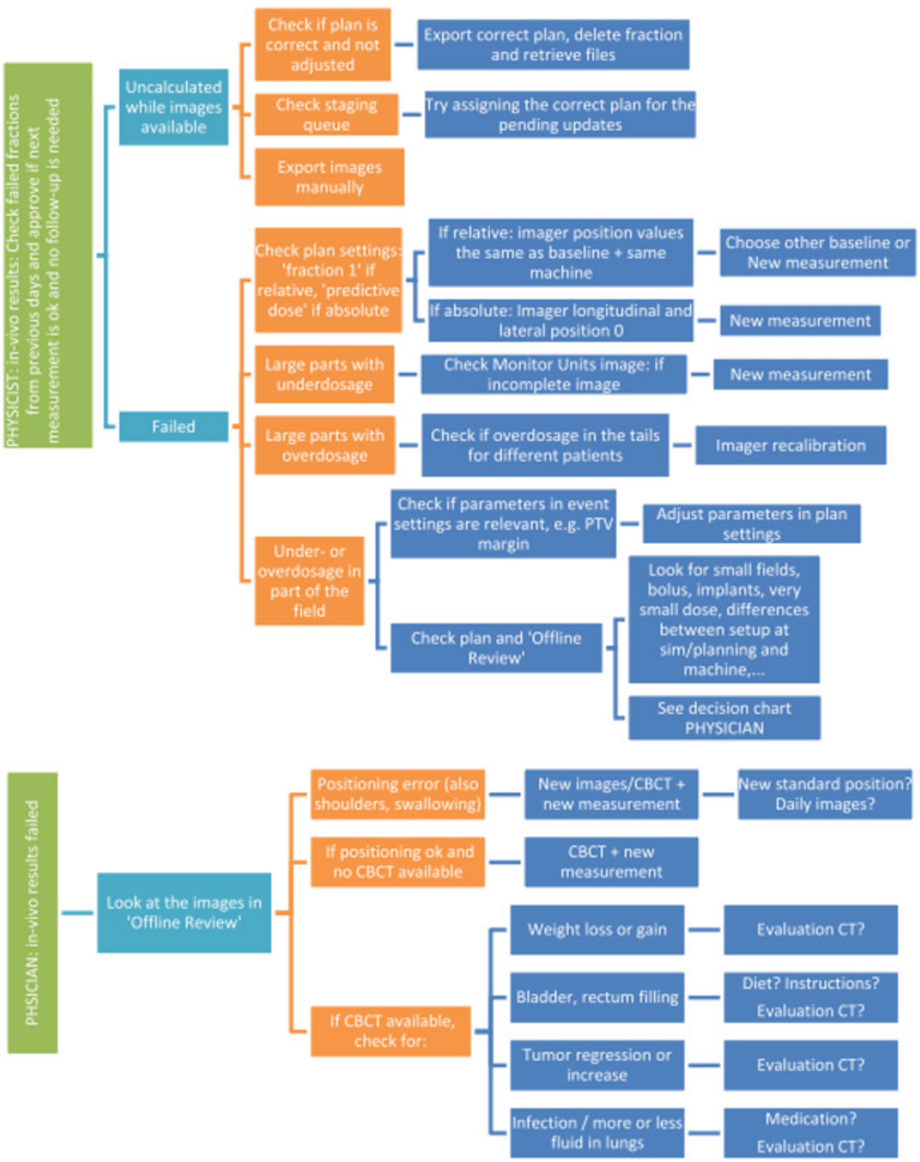


Fig. A1. Decision charts for when a measurement is out of tolerance. The first decision chart is meant for physicists including detecting false positives, the second decision chart is meant for physicians to take actions for patient related errors. Results are always compared with the available imaging. Taking Cone Beam Computed Tomography (CBCT) is often one of the first actions.

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

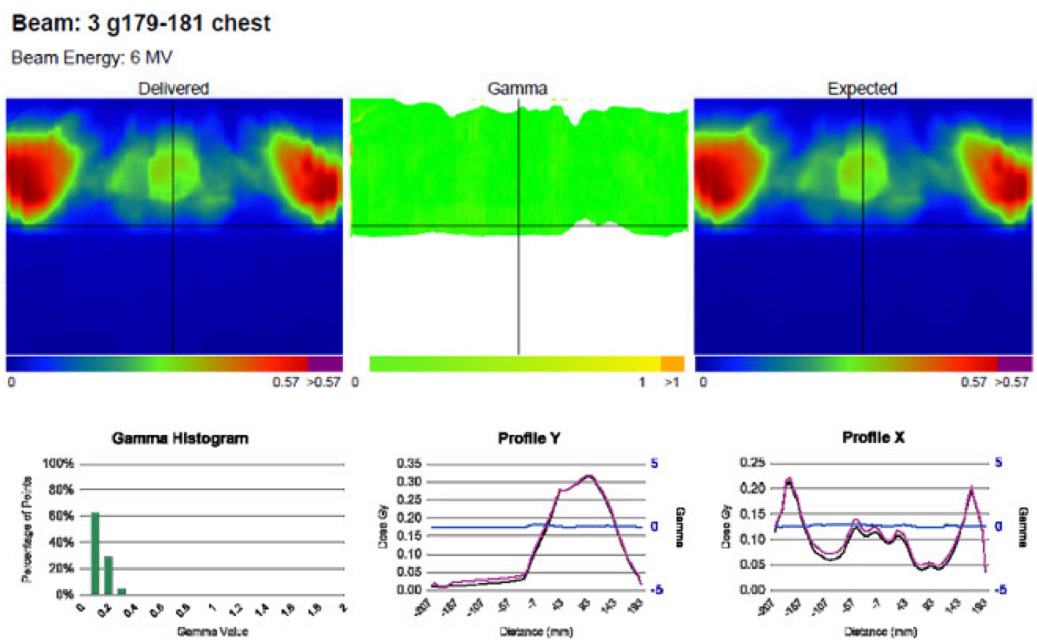
A. Mans, et al., The Netherlands Cancer Institute-Antoni van Leeuwenhoek Hospital, Amsterdam, NL, Med Phys. 2010 Jun; 37(6):2638-44

- 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
- *"Futhermore, 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."*

Investigation Into the Relationship Patient Setup Accuracy and In-Vivo Transit Dosimetry for Image-Guided Volumetrically Modulated Total Body Irradiation (TBI)

S. Taneja, et al., NYU Langone Medical Center, New York, NY, AAPM 2021, TH-F-TRACK 3-6

- *"Purpose: This work explores the relationship between patient setup accuracy with transit in-vivo dosimetry."*
- *"Methods: A total of 192 fields were investigated. Each VMAT plan consisted of four isocenters: head, chest, abdomen, and pelvis. …Transit dosimetry was measured per arc, and analyzed using SNC PerFRACTION with a gamma criteria of 10%/5mm, 5%/5mm, and 5%/7mm."*
- *"Results: Transit dosimetry showed that the average pass rate across all fields was 99.6%, 97.0%, and 99.2% for 10%/5mm, 5%/5mm, and 5%/7mm gamma criteria, respectively."*
- *"Conclusion: Transit dosimetry showed high pass rates using our couch residual tolerances, which confirmed the plan uncertainty analysis performed during treatment planning."*



In vivo dosimetry for patients with prostate cancer to assess possible impact of bladder and rectum preparation

Y. Fiagan et al., Iridium Netwerk, Radiation Oncology Department, Belgium, Technical Innovations & Patient Support in Radiation Oncology 16 (2020) 65–69

- Iridium Kankernetwork used their established in vivo program to evaluate whether at home nurse coaching would improve compliance with Bladder & Rectum filling
- Chose 5%/5mm/95% as the appropriate criteria based on previous studies
- *"It is recommended by both the International Atomic Energy Agency (IAEA) and the European Society for Radiotherapy and Oncology (ESTRO) that in vivo dosimetry (IVD) be used in standard practice of radiotherapy (RT) departments."*
- *"Conclusion: Two dimensional EPID-based IVD successfully detected bladder and rectum filling deviations when an appropriate gamma index and passing rate was implemented."*
- Home nursing care did not appear to help compliance.

SunCHECK™ Patient – PerFRACTION™ Pre-Treatment QA Studies

Novel strategy with the automatic non-coplanar volumetric-modulated arc therapy for angiosarcoma of the scalp

S. Inui, et al., Department of Radiation Oncology, Osaka International Cancer Institute, Osaka, JP, Radiat Oncol 15, 175 (2020)

- Used PerFRACTION 2D for pre-Treatment QA of Head & Neck Patients
- Compared HyperArc plans to VMAT plans using 2%/2mm criteria
- *"The mean gamma pass rates with 3%/2mm and 2%/2mm criteria in the VMAT-FF, HyperArc-FF, and HyperArc-FFF plans were 99.97% ± 0.01% and 99.95% ± 0.04%, 99.88% ± 0.21% and 99.28% ± 1.06%, and 99.74% ± 0.31% and 99.07% ± 0.99%, respectively."*

Treatment planning of VMAT and step-and-shoot IMRT delivery techniques for single fraction spine SBRT: An intercomparative dosimetric analysis and phantom-based quality assurance measurements

Z. Ouyang, et al., Department of Radiation Oncology, Taussig Cancer Institute, Cleveland Clinic, Cleveland, OH, U.S., J Appl Clin Med Phys 2020; 21:1: 62–68

- Retrospective study of methods for Spinal SBRT using PerFRACTION 3D

SunCHECK™ Patient – Efficiency & Ease-of-Use

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."*

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, Los Angeles, CA, U.S., 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."*

Establishing a Routine Clinical Dose Verification Workflow Utilizing CBCT Imaging and Log Files

G Kuzmin, et al, The Cleveland Clinic Foundation, Cleveland, OH, PO-GeP-M-187, AAPM 2020

- Study validating CBCT calculations for PerFraction SBRT cases
- *"Conclusion: Results from this study show that it is clinically feasible to use CBCT images in a clinical dose verification workflow. Since the images and log files are routinely acquired, and CT-CBCT fusion and dose calculation is automated, there is practically no additional burden to utilizing this method routinely."*

Phantom-Based Patient-Specific QA
ArcCHECK® Accuracy & Sensitivity Studies

The effect of measurement geometry on patient specific QA pass/fail rates for stereotactic body radiation therapy (SBRT) Plans

C. Hadsell, et al, University of Wisconsin, Madison, WI, U.S., Medical Dosimetry, 2021

- Paper introduced known errors into two PSQA geometries – centralized (representing Delta 4 and PTW arrays) and peripheral (representing ArcCHECK dimensions)
- *"It was found that centralized geometries resulted in more lenient dose tolerances and less complex sampled dose distributions compared to peripheral geometries. Pass rates were uniformly lower in the peripheral measurement geometry, and the difference in pass rates between the geometries correlated strongly with the difference in dose tolerance and weakly with the difference in the chosen complexity metrics."*
- *"...all (plans) had D95 PTV variations of roughly 5%"*
- *"Upon evaluating the dose gradients for each geometry, it was evident that the 2D dose distributions sampled from the 3D dose in the phantom were more complex for the peripheral geometry when compared to the centralized geometry."*

Table 2
The lung and soft tissue average pass rates for plans with clinically relevant errors

Lung			
gamma tolerances	Peripheral		
	1%	2%	3%
1 mm	65.6 ± 9.0%	75.8 ± 7.2%	82 ± 7.1%
2 mm	83.8 ± 9.7%	89.2 ± 7.3%	92.1 ± 6.0%
3 mm	91.4 ± 6.0%	94.7 ± 4.0%	96.0 ± 3.5%
Gamma tolerances	Centralized		
	1%	2%	3%
1 mm	67.2 ± 8.3%	82.4 ± 6.3%	89.8 ± 4.4%
2 mm	86.8 ± 6.8%	93.8 ± 4.0%	97.0 ± 2.7%
3 mm	93.9 ± 3.4%	97.2 ± 2.5%	98.6 ± 2.0%
Soft Tissue			
Gamma tolerances	Peripheral		
	1%	2%	3%
1 mm	61.9 ± 4.5%	72.8 ± 3.1%	81.2 ± 3.2%
2 mm	82.7 ± 3.3%	88.6 ± 1.1%	92.5 ± 0.8%
3 mm	91.0 ± 2.3%	94.4 ± 1.2%	96.5 ± 0.7%
Gamma tolerances	Centralized		
	1%	2%	3%
1 mm	65.8 ± 5.6%	82.1 ± 6.0%	89.3 ± 3.9%
2 mm	85.1 ± 4.4%	92.6 ± 4.3%	95.5 ± 3.1%
3 mm	92.1 ± 3.3%	95.9 ± 2.9%	97.4 ± 2.4%

A comparison of the gamma index analysis in various commercial IMRT/VMAT QA systems

M. Hussein, et al., Royal Surrey County Hospital, Guildford, UK, Radiotherapy and Oncology 109 (2013) 370–376

- Study comparing ArcCHECK, and other commercial devices, plus 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

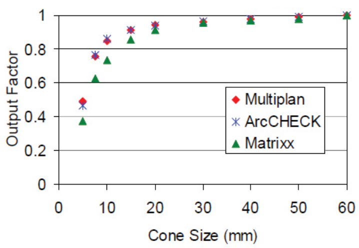
J. Kozelka, V. Feygelman, Sun Nuclear Corporation, Melbourne, FL. U.S.; H. Lee Moffitt Cancer Center, Tampa, FL, U.S.; Med. Phys. 38 (9), (2011)

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

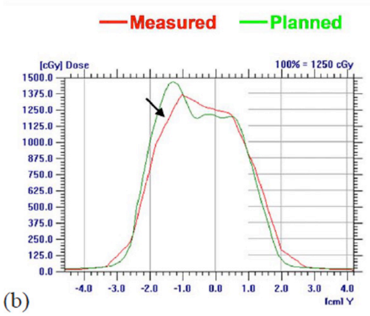
Robotic radiosurgery system patient-specific QA for extracranial treatments using the planar ion chamber array and the cylindrical diode array

M. Lin, et al., Univ of Maryland School of Medicine, Baltimore, MD, U.S., 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



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

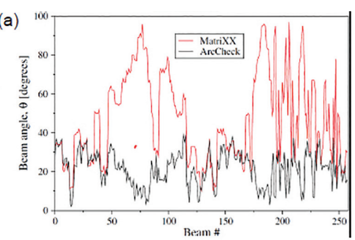


(b)

"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."

  - 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."*

(a)

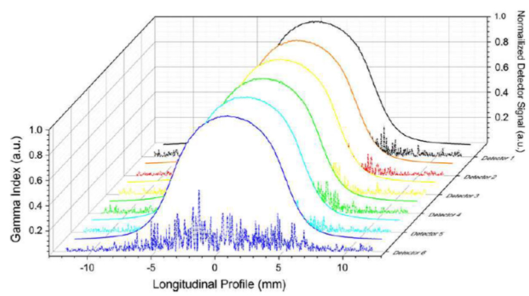


"The maximum angular correction for a given beam is 8.2% for the MatriXX and 2.4% for the ArcCHECK system, respectively."

Filmless methods for quality assurance of Tomotherapy using ArcCHECK

B. Yang, et al., Medical Physics and Research Department, Hong Kong Sanatorium & Hospital, 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

V. Mhatre, et al., Kokilaben Dhirubhai Ambani Hospital & Medical Research Institute, 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."*

TABLE I. Results of gantry angle measured by ArcCheck for both helical and static star shot tests.

		ArcCHECK result		
	Expected angle (°)	Mean (°)	SD (°)	Difference (°)
Helical	0	359.9	0.3	−0.1
	120	119.9	0.2	−0.1
	240	239.8	0.2	−0.2
Static	0	0.0	0.5	0.0
	45	44.8	0.5	−0.2
	135	134.6	0.5	−0.4

ArcCHECK® Studies on the Varian Medical Systems® Halcyon™ System

Unlocking a closed system: dosimetric commissioning of a ring gantry linear accelerator in a multivendor environment

A. Saini, H. Lee Moffitt Cancer Center, Tampa, FL, U.S., J Appl Clin Med Phys 2021; 22:2:21–34

- ArcCHECK results of TG-119 tests were analyzed at 3/2/global and 2/2/local
- *"All our ArcCHECK results exceed the standard TG-218 recommendations, that is, gamma analysis passing rates ≥95% for the 3% G/2 mm/10% criteria combination. The average passing rate was 99.3 +/- 0.5%, generally comparing favorably to 99.1 +/-0.9% with Eclipse"*

Table 2 Ion Chamber dose agreement, ArcCHECK gamma analysis and median/mean dose differences. All dose differences reported as Measured minus RayStation Calculated.

	ΔD Meas. -TPS (%)		γ pass rate (%)					
Plan	P High	P low	3%G/2 mm	3%L/2 mm	2%L/2 mm	Median D (%)	Ave D (%)	MU
Cshape VMAT	-0.4%	0.0%	99.5	93.8	91.1	0.2	-0.2	1388
ABD VMAT	-0.1%	0.8%	100.0	98.2	96.3	-0.4	-0.1	358
ANAL VMAT	0.4%	0.5%	99.7	93.5	92.4	0.3	-0.5	1257
HN VMAT	0.5%	-1.7%	99.9	94.1	90.9	0.9	0.7	629
ProstBed VMAT	-0.1%	0.9%	99.7	96.8	94.4	0.6	0.5	610
Ave	0.1%	0.1%	99.8	95.3	93.0	0.3	0.1	848
SD	0.4%	1.1%	0.2	2.1	2.3	0.5	0.5	
Cshape SW VMAT	0.5%	0.0%	99.1	91.1	89.7	0.4	-0.3	1844
ABD SW VMAT	0.7%	-1.0%	99.1	93.0	90.2	0.7	0.3	1075
ANAL SW VMAT	0.6%	0.5%	98.9	92.5	89.6	0.3	-0.3	1183
HN SW VMAT	0.2%	1.0%	98.2	87.2	81.8	1.2	0.8	1655
ProstBed SW VMAT	0.1%	1.4%	99.8	93.5	89.6	1.2	0.8	1574
Ave	0.4%	0.4%	99.0	91.5	88.2	0.8	0.3	1466
SD	0.2%	1.0%	0.6	2.5	3.6	0.4	0.6	
Cshape DMLC	-0.7%	-4.0%	98.6	95.9	94.3	0.3	-0.4	1151
ABD DMLC	0.6%	-1.2%	99.0	93.7	88.8	0.9	0.6	1073
ANAL DMLC	0.8%	-0.1%	98.6	94.3	92.2	-0.2	-0.6	1513
HN DMLC	0.7%	-0.5%	99.3	92.8	87.6	1.6	0.8	1243
ProstBed DMLC	-1.3%	0.6%	99.7	95.9	92.6	0.4	-0.5	1389
Ave	0.0%	-1.0%	99.0	94.5	91.1	0.6	0.0	1273
SD	1.0%	1.8%	0.5	1.4	2.8	0.7	0.7	
Overall Ave	0.2%	-0.2%	99.3	93.8	90.8	0.6	0.1	
SD	0.6%	1.4%	0.5	2.6	3.4	0.5	0.5	
IC Ave High and Low	0.0%							
SD	1.1%							

- Standard DC/PF models used
- Compared to Raystation Monte Carlo and Eclipse
- *"With the standard 3%G/2 mm criteria and 10% cutoff threshold, the average passing rate for 15 plans was 99.9% 0.1% (range 99.8%–100%). Tightening the criteria to 2%L/2 mm resulted in the average passing rate of 98.5 0.8% (range 97.1%–100%)."*

Comprehensive validation of halcyon 2.0 plans and the implementation of patient specific QA with multiple detector platforms

E. Laugeman, Washington University Medical Center – Siteman Cancer Centre, St. Louis, MO, U.S., J Appl Clin Med Phys. 2020 Jul;21(7):39-48. doi: 10.1002/acm2.12881. Epub 2020 May 5.

Commissioning and performance testing of the first prototype of AlignRT InBore™, a Halcyon™ AND Ethos™ dedicated surface guided radiation therapy platform

D. Nguyen, et al., Radiotherapy centers of ORLAM group, Macon, FR, Physica Medica 80 (2020) 159–166

- Validates Varian Medical Systems® Halcyon™ System, Ethos™ Therapy, and SGRT using ArcCHECK and SRS MapCHECK

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 Varian Medical Systems® Halcyon™ System beam models at two centers using ArcCHECK, Daily QA 3, IC PROFILER, EDGE Detector and other vendors' devices.

ArcCHECK® Studies on the Accuray Radixact™ System

A pre-treatment quality assurance survey on patients treated with the new Accuray Radixact platform

M. Fusella, et al, PO-1768, ESTRO 2020

- Summary – Radixact validation using ArcCHECK
- *"Objective: Pre-treatment patient specific quality assurance is a necessary task to ensure accurate dose delivery. When a new machine became operational all the clinically approved plans must undergo a dosimetric verification."*
- *"…this is the first study on performances evaluation of the Radixact platform and Precision TPS…"*

Clinical implementation of RayStation for Accuray Radixact tomotherapy platform

M. Fusella, et al, PO 1368, ESTRO 2020

- Summary – ArcCHECK used to validate RayStation™ commissioning of Accuray Radixact
- *"Purpose: Accuray Radixact has been recently installed at our Institute. Alternatively to Precision TPS, we acquired RaySearch TPS (RayStation) for tomotherapy planning. The commissioning and testing of the new TPS is here presented."*

3DVH® Studies

VMAT QA: Measurement-guided 4D dose reconstruction on a patient

B. Nelms, et al., Canis Lupus LLC, Merrimac, WI, U.S., Med. Phys. 39, (2012)

- 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

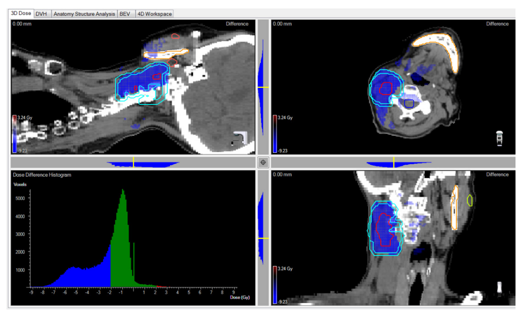
H. Zhen, et al., Department of Medical Physics, University of Wisconsin, Madison, WI, U.S., Med. Phys. 38, (2011)

- 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

B. Nelms, et al., Canis Lupus LLC, Merrimac, WI, U.S., Med. Phys. 40 (11), (2013)

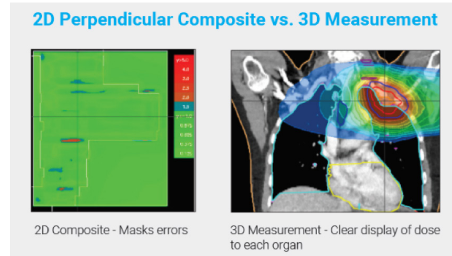
- Four separate hospitals submitted an article on errors they discovered using 3DVH but were missed by conventional planar Gamma analysis.



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., Department of Radiation Oncology, University of Colorado School of Medicine, Aurora, CO, U.S., Med. Phys. 45 (4), April 2018

- Recommends 3D QA (such as ArcCHECK, 3DVH, or PerFRACTION) in order to cover the entire clinical treatment area

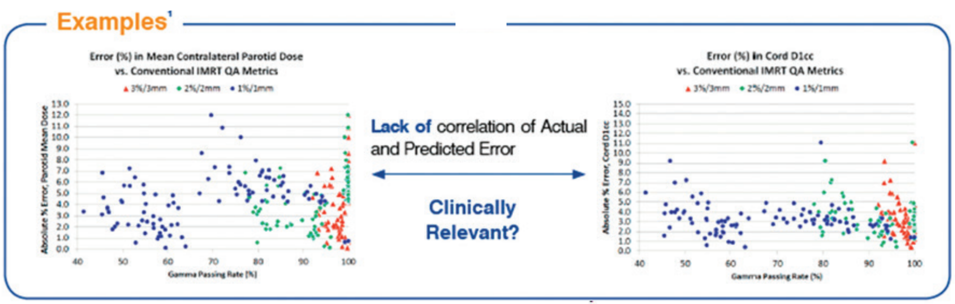
Using a Novel Dose QA Tool to Quantify the Impact of Systematic Errors Otherwise Undetected by Conventional QA Methods: Clinical Head and Neck Case Studies

MF Chan, et al., Memorial Sloan-Kettering Cancer Center, New York, NY, U.S., Technol Cancer Res Treat. 2014 Feb;13(1):57-67

- *"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

B. Nelms et al., Canis Lupis, LLC, Merrimac, WI, U.S., Med. Phys. 38, (2011)

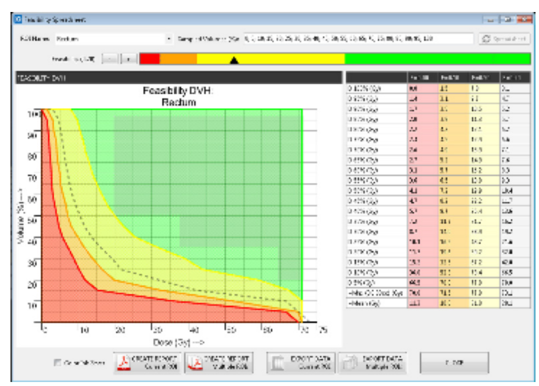


PlanIQ™ Accuracy Studies

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

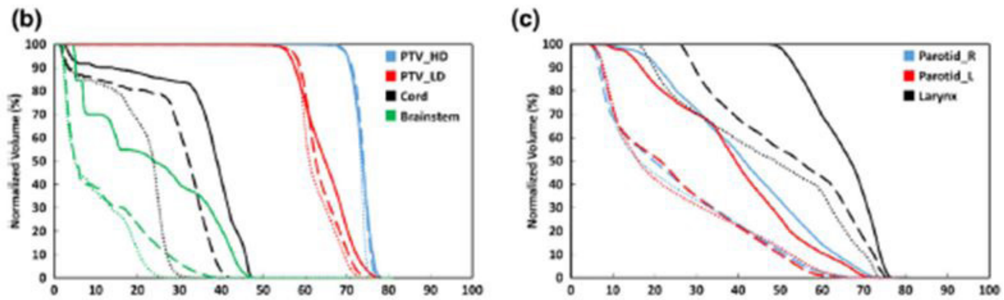
- This study evaluated the ability of Plan IQ to generate custom OAR constraints per patient anatomy, document them, and improve plan quality
- *Conclusion: "Pinnacle Auto-Planning combined with Plan IQ produced superior plans than manually planned or Auto-Planning with "generic" constraints on a faster timeline." (saved an average of 3.5 hours per optimization)*



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

S. Ahmed, et al., Department of Physics, University of South Florida, Tampa, FL, U.S., Med Phys 2017; 44(10):5486-5497

- *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

D. Fried, et al., Department of Radiation Oncology, University of North Carolina at Chapel Hill, Chapel Hill, NC, U.S., Radiation Oncology Physics 2017; 18(5):245-250

- *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., Canis Lupus LLC, Merrimac, WI, U.S., Practical Radiation Oncology 2012

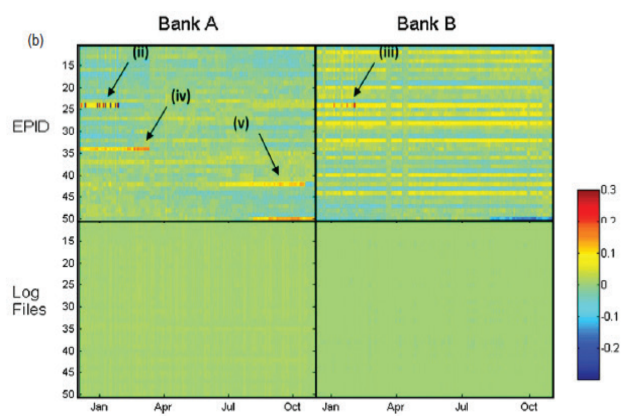
- *"There is a large inter-planner variation in plan quality as defined by a quantitative PQM score that measures the ability of the planner to meet very specific plan objectives."*

Why is Independence Important?

Monitoring daily MLC positional errors using trajectory log files and EPID measurements for IMRT and VMAT Deliveries

A. Agnew, et al., Radiotherapy Physics, Northern Ireland Cancer Centre, Belfast Health and Social Care Trust, Northern Ireland, UK, Phys. Med. Biol. 59, (2014)

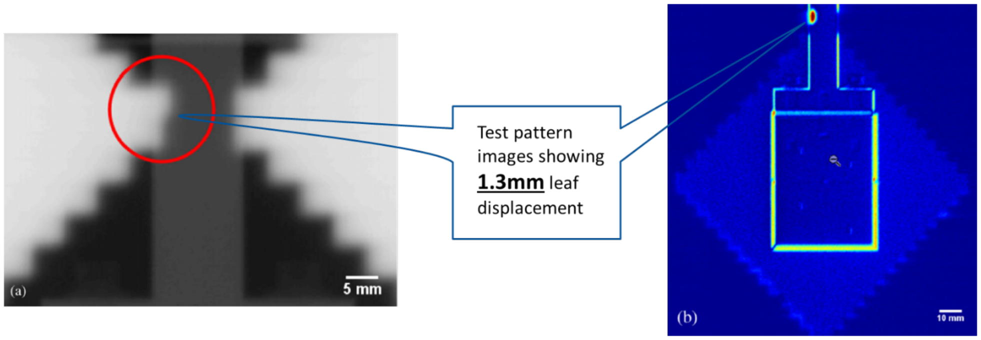
- *Study method - One year of MLC picket fence data from 2 TrueBeams' Trajectory log files vs. EPID images.*
- *"Over the duration of the study, multiple MLC positional errors were detected using the EPID based software but these same errors were not detected using the trajectory log files."*
- *"In 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

B. Neal, et al., Department of Radiation Oncology, University of Virginia, Charlottesville, VA, U.S., 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."*



Report of AAPM Task Group 219 on independent calculation-based dose/MU verification for IMRT

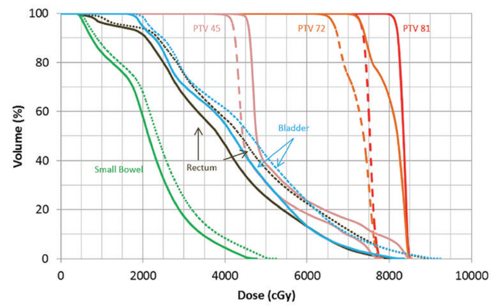
T. Zhu, et al., University of Pennsylvania, Philadelphia, PA, U.S., Medical Physics. 2021;00:1–22.

- *"Physicists should not rely solely on independent dose/MU calculation tools for IMRT quality assurance. Such software currently cannot detect errors in dose calibration, MLC errors, collimator or gantry discrepancies or patient setup inaccuracies."*
- *"Independent dose/MU calculation can be only part of a more comprehensive QA program for IMRT & VMAT in a department because of the limitations of secondary dose/MU software."*

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."*



Practice Changes

Professional practice changes in radiotherapy physics during the COVID-19 pandemic

J. Bertholet, et al, Bern University Hospital, University of Bern, Switzerland, Physics and Imaging in Radiation Oncology, 2021 Jul; 19: 25–32.

- *"Results: The majority of MPs worked in alternation at home/on-site. Among practice changes, implementation and/or increased use of hypofractionation was the most common (47% of the respondents). Sixteen percent of respondents modified patient-specific quality assurance (QA), 21% reduced machine QA, and 25% moved machine QA to weekends/evenings."*

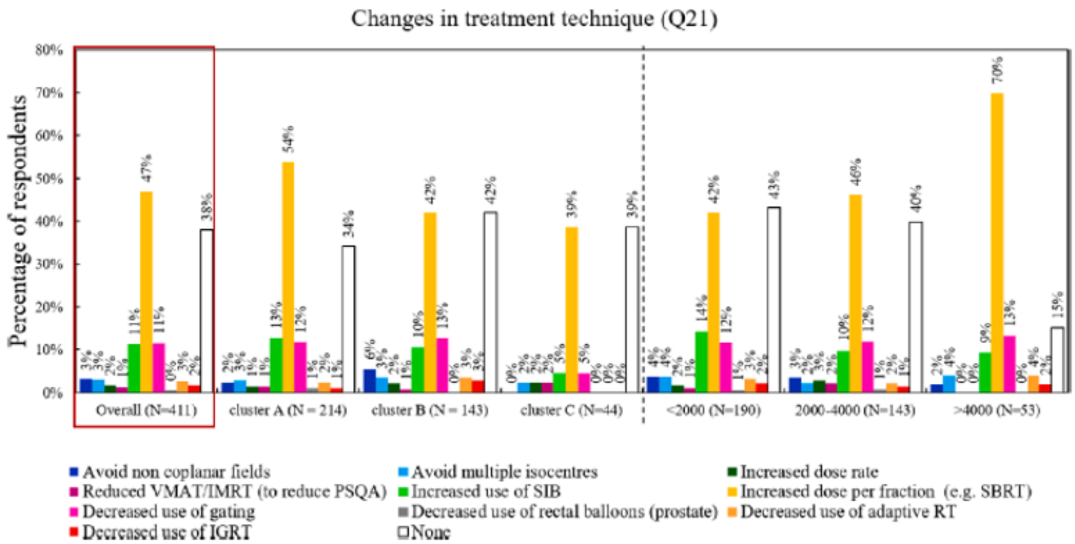


Fig. 1. Changes in treatment technique (Q21) overall (red box), by country cluster (left of the dotted line) and by centre size in patients treated per year (right of the dotted line). Ten responses not associated to any cluster and 25 responses without an answer for the number of patients treated per year are only included in the "Overall" group. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Looking for Patient-Specific Stereotactic QA Publications? See our Small Field QA Key Publications document.