EPID DOSIMETRY IN SunCHECK™ PATIENT

EPID Calibration, Pre-Treatment QA
and In-Vivo Monitoring

SUN NUCLEAR corporation

Introduction

The field of radiation oncology continues to advance toward true end-to-end patient treatment QA and verification, thanks in large part to the near-ubiquitous presence of electronic portal imaging devices (EPIDs) on modern linear accelerators.

Though advances have been made in EPID panel technology, they remain first and foremost imagers and not dosimeters. Thus, special considerations must be accounted for when attempting to use EPIDs for absolute dose measurements.

EPID dosimetry can be broken into two primary delivery techniques: in air or "direct" irradiation of the panel, typically used for imaging QA and pre-treatment patient QA, and "transit" irradiation through the patient (or phantom), used for positioning and treatment delivery verification, i.e. in-vivo QA. Both present challenges for accurate calibration to absolute dose. Questions of panel material response, traceability to a validated calibration protocol, etc., arise and must be answered.

Transit dosimetry has historically presented the greater challenge for accurate dosimetry, due to the increased scatter to the panel and other confounding factors specific to transit conditions. In fact, previous solutions for calibrating transit dosimetry often involved many hours to days of rigorous and complex data collection, sometimes even requiring liquid water tanks precariously balanced over the EPID panel and filled or emptied to create different path lengths. Even once the data is collected, the process of analyzing and modeling it could take additional days if not weeks or months before the method could be put to clinical use.

Within SunCHECK™ Patient (PerFRACTION™ module), the goal has always been to include rigorous physics analysis while streamlining the calibration process to minimize the amount of time and effort required of physicists to collect the calibration data.

Calibration Method

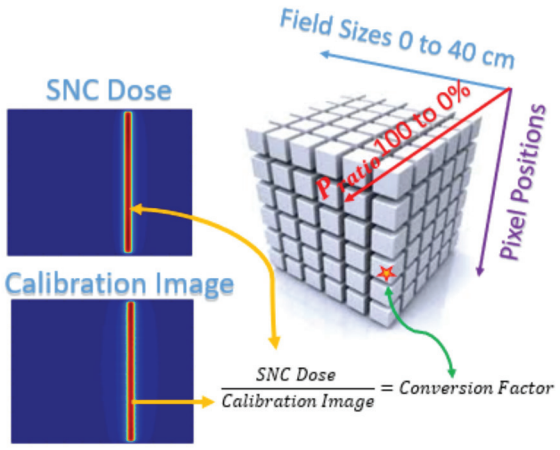
To accommodate the two delivery methods for EPID dosimetry, SunCHECK Patient currently employs two separate but related calibration workflows, one delivered in air only, and the other through a series of varying buildup thicknesses. The same basic patent-pending methodology underlies both calibration routines.

In each, the calibration beams—a series of rectangular fields of varying widths and positions—are delivered to the EPID and the images are captured. The in-air calibration for pre-treatment QA is, as the description implies, delivered directly to the EPID with the couch fully retracted. The transit calibration for in-vivo QA delivers fields to three thicknesses of Solid Water™ (or equivalent): 30 cm, 10 cm, and 0 cm (air). The images for all beams are then sent for processing. Conversion of EPID images to dose is achieved through two general steps. First, a master calibration table of dose-per-signal (DPS) values is built using the dose calculated for the calibration fields in a virtual water slab centered on the plane of the EPID. The DPS table is built as a function of radiological pathlength (RP) and EPID-to-phantom distance (EPD). Then, for each patient plan, control point-by-control point RP and EPD values are derived via a ray-trace from the linac head through air (pre-treatment) or the patient's planning CT (in-vivo) to the EPID panel. This allows indexing into the master table and extraction of the expected dose-per-signal value for each control point. That DPS result is multiplied by the measured signal for each pixel to produce a map of the measured dose in the plane of the EPID.

The conversion factors are created as follows:

For each EPID pixel: Absolute Dose = conversion matrix (P, EFS, P_{ratio}) * EPID Response, where P = pixel position, EFS = effective field size, P_{ratio} = Primary Signal Ratio.

The first dimension of the conversion matrix is determined by simply dividing the computed dose value for each pixel by the EPID response for that pixel.



Next, every two calibration fields' images and doses are combined using different weights in order to calculate the conversion factors for different (P_{ratio}) *See Fig. A*

Finally, all pixel responses and doses are stored. At the end of the calibration processing a linear fit is created, and the slope of the linear fit is considered the conversion factor. This process is repeated for each phantom thickness and detector distance combination and the resulting matrix is stored in the SunCHECK database. *See Fig. B*

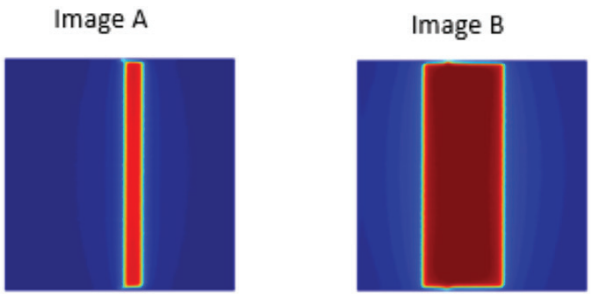


Fig. A

Creating Plan-Specific Factors

When a new patient plan is received by the software, the conversion factors for pre-treatment and in-vivo measurements are pre-calculated to facilitate faster results processing once EPID images are collected. At each pixel position the P_{ratio} and effective field width from each segment of the beam are determined, along with radiological path length (via ray trace), and expected detector distance and the relevant conversion factor is extracted from the calibration matrix. A weighted average of the conversion factors over all segments for each pixel is calculated and the result is stored in the SunCHECK database.

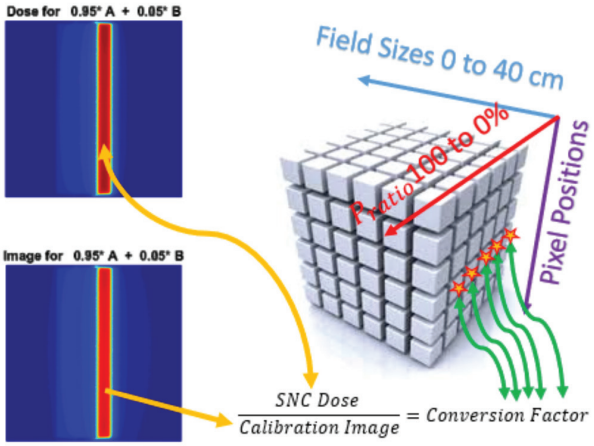


Fig. B

Upon receipt of an EPID image from the plan delivery, first the system determines whether it was delivered in air or in- vivo, and then the appropriate map of signal-to-dose conversion factors is applied to the measured image to generate the measured dose map in the plane of the EPID. *See Fig. C*

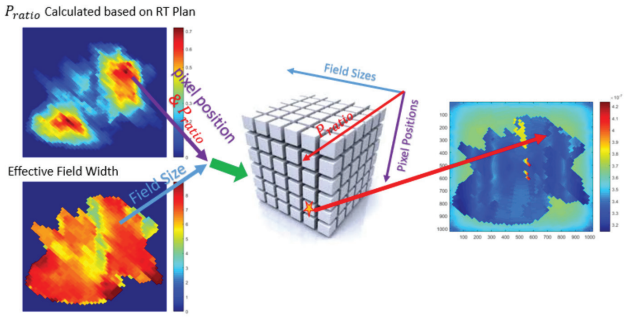


Fig. C

Creating Predicted Dose Images

A Predicted Dose image for each beam in a patient plan is also generated in advance upon import of the plan and stored for later comparison to the converted EPID images. The Predicted Dose is created for pre-treatment deliveries in air by calculating the dose from the RT Plan into a virtual water slab phantom at the plane of the EPID. For in vivo deliveries, the beams are projected through the patient's planning CT before calculating the resultant exit dose in the water slab phantom. (This necessitates rotating the water slab phantom around the patient anatomy, especially for VMAT plans, in order to simulate the EPID remaining perpendicular to and opposite of the gantry head.) *See Fig. D*

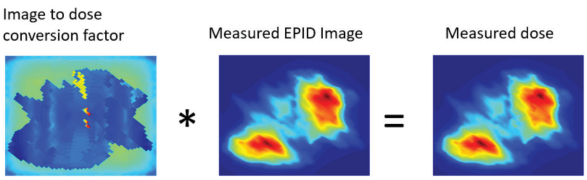


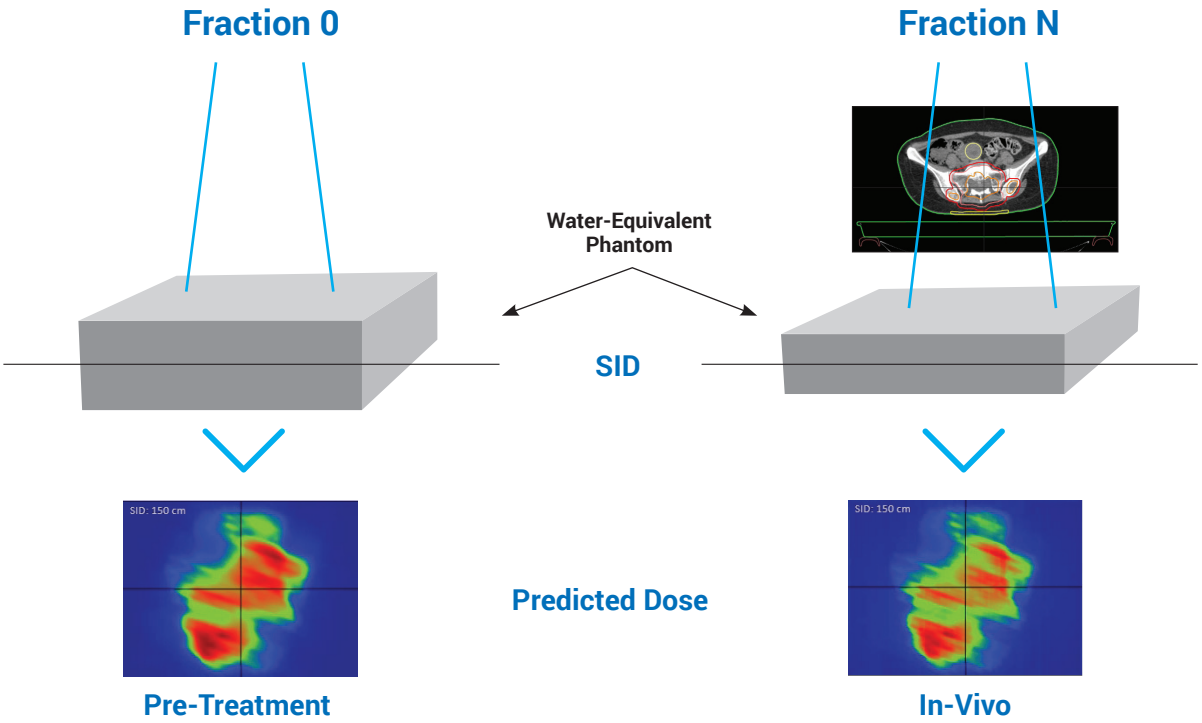
Fig. D

Job Processing and Workflow

In keeping with the objective to streamline the calibration process as much as possible while retaining rigor, the automation pathways, including DICOM association, within the SunCHECK Platform are leveraged to generate, retrieve, and process the imaging data.

The first step is to generate a calibration plan for delivery. The user specifies an energy and SID configuration, nominal dose rate, and (optional) a desired "QA patient" name and medical record number. Using this information and the DICOM machine name, MLC model, and EPID panel model information from the SunCHECK Machine configuration page, a custom DICOM RT Plan is generated for the user's machine which contains all the necessary fields for calibration delivery. The user simply exports the calibration plan to their Record & Verify (R&V) system, adds imaging, and loads the fields at the accelerator.

Upon export of the plan to the R&V system, SunCHECK Patient (PerFRACTION module) also initiates the calculation of the Predicted Doses for each calibration field in the virtual water slab phantom using the validated, TPS-quality collapsed cone superposition/convolution dose calculation algorithm [Ahmed, Saeed & Hunt, Dylan & Kapatoes, Jeff & Hayward, Robert & Zhang, Geoffrey & Moros, Eduardo & Feygelman, Vladimir. (2017). Validation of a GPU-Based 3D dose calculator for modulated beams. Journal of applied clinical medical physics. 18. 10.1002/acm2.12074] and stores them in anticipation of the calibration delivery.



EPID Dosimetry in SunCHECK™ Patient

Pre-Treatment QA and In-Vivo Monitoring // PerFRACTION™ Module

Delivery of the calibration plan on the linear accelerator typically takes around 30-45 minutes, depending on machine configuration and console workflow. This is the only time directly required of the physicist. The data retrieval automation of SunCHECK collects the images and, using the DICOM header information, associates them to the calibration plan.

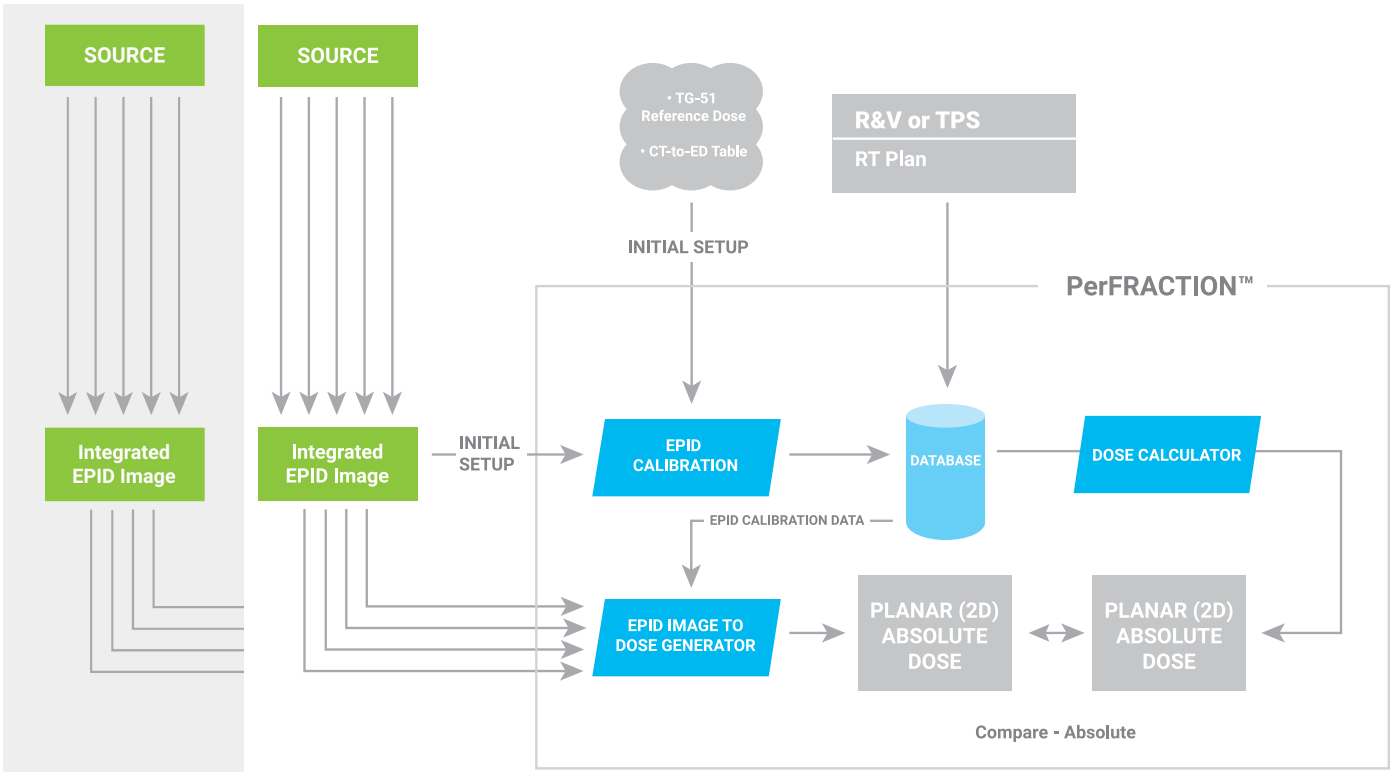
The signal-to-dose conversion factors are then generated as described above, in a process that typically takes approximately an hour (often less) and can be left to run in the background. The calibration results are then validated by converting each of the EPID images to dose using the newly generated conversion factors and comparing them to the Predicted Dose maps from the virtual water phantom.

When the calculations and comparisons are complete, the physicist reviews the overall pass rate and (optionally) the beam-by-beam results and accepts the calibration. EPID dosimetry analysis now becomes active for all new incoming patient plans at that energy on that machine.

Upon receipt of a new plan by the system, several steps are taken. After the initial SunCHECK Patient secondary calculation (DoseCHECK™ module), the plan-specific conversion factors for both pre-treatment QA and in-vivo monitoring are generated and stored in the database. Predicted Dose maps for the plan in air and projected through the planning CT are also created and stored (as described above).

When delivery occurs, integrated EPID images are collected on the machine, retrieved by SunCHECK, and identified as either in air or in-vivo then automatically converted to dose using the appropriate stored conversion factors. Finally, the measured dose maps are compared to the Predicted Doses generated for the plan using one of five comparison methods available in the software, most commonly gamma or percent difference, with the settings and tolerances established by the user. If the results of the comparison do not meet the user's criteria, the event is marked accordingly and an email notification may be sent alerting the user to the failure.

This process can occur simultaneously with the 3D dose reconstruction available in the PerFRACTION module, to provide multiple ways to visualize and analyze the delivery efficacy for any given treatment.



Conclusion

The SunCHECK Patient PerFRACTION module offers EPID-based absolute dosimetric analysis options for both pre-treatment QA and in-vivo monitoring, the latter accounting for changes in patient position and anatomy between treatment fractions in addition to the machine performance verification offered by both methods.

With the increasing demand for measurement of dose actually delivered to the patient – for example, as mandated in the European Union through 2013/59/EURATOM Article 83, which became enforceable in February 2018 – SunCHECK Patient provides a solution which is conceptually robust, feasible for clinical use, and efficient in implementation.

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