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One-Shot Automated Constancy Testing of Halcyon kV Planar Imaging with Phantom Metrics and Entrance-Dose Tracking

Markus Bach, PhD
Strahlentherapie Köln-Kalk, Cologne, Germany

ABSTRACT

Purpose: To develop and clinically evaluate an automated, objective monthly constancy-testing workflow for Halcyon kV planar imaging using a single service-mode acquisition of a PTW NORMI 4 FLU phantom combined with an external entrance-dose measurement (PTW CONNY II), aligned with AAPM recommendations for accelerator imaging QA implementation and imaging-dose management (TG-142/TG-198/TG-75) and using a geometry–image-quality–dose constancy concept (TG-179).

Methods: Monthly kV XI images were acquired in service mode (125 kV, 20 mA, 20 ms, 1×1 binning; system-reported dose 0.036 mGy). A Python pipeline imports the XIM image, performs rigid registration to a baseline, applies fixed ROIs, and automatically extracts: (i) spatial resolution from the line-pair test pattern (limiting resolution, lp/mm); (ii) gray-scale/dynamic range from the step wedge by verifying visibility and separation across all 17 steps; (iii) geometric constancy from predefined distance measurements; and (iv) entrance dose using CONNY II positioned in front of the phantom. The submitted overview figure documents the ROIs and measurement geometry (line, arc, and distance overlays). Results are exported as a standardized PDF and appended to date-sorted CSV and Excel (XLSX) logs for trending.

Results: Over >6 months of monthly measurements, the automated analysis consistently detected all 17 step-wedge levels and reported limiting spatial resolution of 1.2–1.4 lp/mm. Measured entrance dose differed by 0–11% relative to the system-reported value. Geometric distance metrics remained stable over time with no systematic drift.

Conclusion: A single Halcyon kV service-mode acquisition enables fully automated, observer-independent extraction of key imaging-QA parameters (resolution, gray-scale/dynamic range, geometry, and dose) with standardized reporting and longitudinal trend tracking.

CONTACT

Markus Bach
Strahlentherapie Köln-Kalk, Cologne, Germany
dr.markus.bach@gmail.com

The analysis runs as a browser application. Contact me for access or collaboration.

INTRODUCTION

Planar kV imaging on Halcyon guides daily patient setup, but its periodic constancy test is usually scored by eye. Visual scoring is observer dependent and detects slow drifts late.
TG-142 asks for monthly checks of scaling, spatial resolution, contrast, uniformity and noise, each against an institution-specific baseline rather than an absolute value. That is exactly the logic of a Konstanzprüfung under the German DIN 6868 series, the standard governing this phantom.
We asked whether one service-mode acquisition of a single phantom, plus one external entrance-dose reading, can cover geometry, image quality and dose fully automatically.

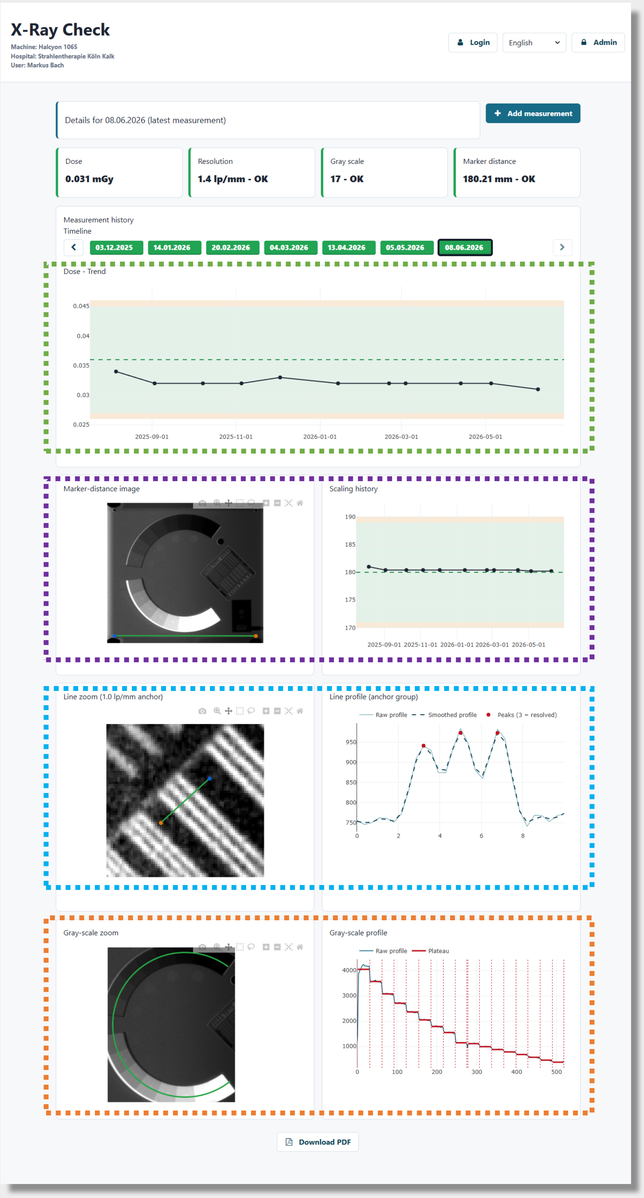
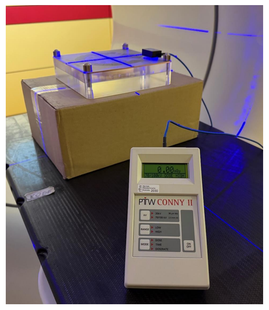


Figure. Automated constancy workflow as a browser application.
Colored frames mark the four analysis regions: spatial resolution (blue) reports the limiting group; gray scale (orange) the 17-step wedge; scaling (violet) the fiducial-marker distance; entrance dose (green) the monthly CONNY II trend against its baseline. The line-pair view is fixed on the 1.0 lp/mm anchor group for trend stability, while the resolution card reports the swept limit of 1.4 lp/mm.

METHODS AND IMPLEMENTATION

Acquisition
PTW NORMI 4 FLU on the couch, PTW CONNY II in the entrance plane, SSD 85 cm. One kV XI service-mode image: 125 kV, 20 mA, 20 ms, 1×1 binning (0.4 mAs); a fixed factor (≈1.31) relates the dose and imaging positions.



Self-calibrating geometry
Four fiducial dots form a rigid 180 × 160 mm rectangle. Their pixel separation over the nominal size gives the magnification of each acquisition directly — no SID or couch model (M = 1.796, 0.187 mm/px in the object plane).
Pipeline
A Python analysis verifies technique against the reference header, registers to the reference, and extracts all metrics from the original pixels. It runs as the browser application shown at right: upload, analyse and store in one step; any past session recomputes on a click. ROIs and tolerances live in a parameter table, so the workflow ports by editing values, not code.

RESULTS

■ Spatial resolution
Every bar group is scored by a lock-in at its own nominal frequency; the fixed line ROI (blue frame) anchors the 1.0 lp/mm group required by DIN, and the card reports the highest group still resolved. The bar-normal angle is fitted from the local spectrum, and the scan runs on the original pixels.
Result: modulation falls 0.10 → 0.09 → 0.06 → 0.04 across the 0.8–1.4 lp/mm groups, placing the limiting resolution at 1.4 lp/mm, in agreement with visual scoring. Sampling limit 2.67 lp/mm.

■ Gray scale
A radially averaged band along the wedge is segmented with edges detected on ln(I), so every step is weighted equally across the dynamic range; on the raw signal a step is 570 counts at the bright end but only 80 at the dark end, and a single threshold would miss the dark transitions.
Result: all 17 wedge levels detected on every session; 15 of 16 transitions pass Weber ≥ 0.05 and CNR ≥ 1. The one failure repeats identically on the reference and every measurement — a phantom property, not an imaging fault.

■ Scaling
Each fiducial dot is located to sub-pixel precision; marker separation is reported in the object plane, with the two rectangle diagonals cross-checked to reject a mis-detected dot and fall back safely.
Result: reproducibility 0.1 px (0.01%) on a 962 px separation, stable across 25 parameter settings; rectangle recovers as 180.0 × 160.0 mm. Phantom height resolved to ~1 mm, rotation (~0.1°) measured — quantities rigid registration cannot see.

■ Entrance dose
The CONNY II reading is trended against a baseline with a ±0.0015 mGy action level (1.5 display digits).
Result: over 11 monthly sessions the probe read 0.032 mGy ×9 and 0.033 mGy ×2 at the fixed dose position — within one display digit. Baseline 0.0322 mGy, slope +0.7%/yr (p = 0.66). The value is a constancy metric against its own baseline, not an absolute dose; the system value (0.0360 mGy) is a computed nominal figure.

DISCUSSION AND CONCLUSIONS

Achievements
- One 0.4 mAs acquisition yields resolution, gray scale, scaling and dose — observer-independent, with standardized PDF and CSV/XLSX logs.
- Fiducial scaling replaces the geometric model: magnification and phantom plane measured per acquisition (0.01%, ~1 mm).
- Lock-in readout makes limiting resolution a computed quantity (1.4 lp/mm); all 17 wedge steps recovered on a single frame via log-domain edge detection.
- TG-142 asks for baselines, not absolutes — a DIN-style Konstanzprüfung satisfies both frameworks with one acquisition.

Automation exposed
- A kV collimator 1 cm off the reference, caught by the header check.
- A wedge transition no method can separate, reproducible across months.
- A 35% modulation loss from resampling — hence resolution is measured on the original pixels.

Limitations
Constancy, not accuracy: the system dose value is computed with an undocumented reference plane, so reproducibility is the meaningful figure. Coordinate coincidence, uniformity and noise remain separate tests; rotation is measured but not corrected.

The workflow is available as a browser application. For access or collaboration, please contact the author.

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