

Machine-Specific Statistical Process Control (SPC) Thresholds for MR-Linac Daily QA Trending

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Objective

Daily QA tolerances are often implemented as fixed pass/fail thresholds, yet MR-Linac performance can be facility-specific and may evolve over time. This study used statistical process control (SPC) to establish global, machine-specific 2σ warning and 3σ action levels for Daily QA3 metrics to support longitudinal trending and early identification of baseline drift.

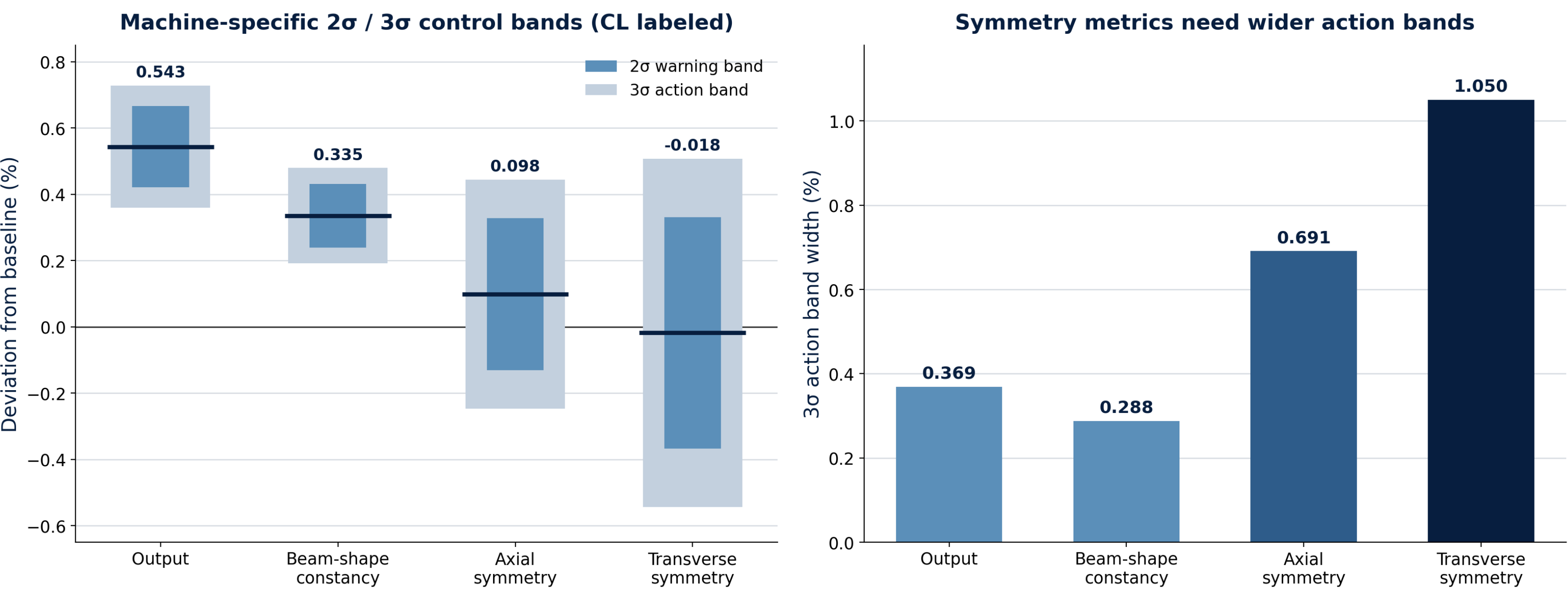
Methods

- ❑ Daily QA3 records from a clinical MR-Linac were retrospectively reviewed (n=567, 2023-03-08 to 2026-01-26). Baseline-referenced (“relative”) metrics included output (%), beam-shape constancy (%), and axial/transverse symmetry (%).
- ❑ For each metric, Individuals–Moving Range (I–MR) SPC was applied across the full dataset. The center line (CL) was defined as the overall mean.
- ❑ Following standard SPC convention, 2σ warning and 3σ action limits were calculated using I–MR constants as $CL \pm 1.77 \cdot MR$ and $CL \pm 2.66 \cdot MR$, respectively, where MR is the mean moving range.

Results

Global I–MR SPC produced a concise set of machine-specific daily-trending thresholds across four baseline-referenced metrics. Output and beam-shape constancy were tightly controlled (center lines 0.543% and 0.335%, with narrow 3σ bands), while axial and transverse symmetry centered near zero (0.098% and –0.018%) but required much wider action bands.

Each metric’s 2σ warning and 3σ action limits form a standardized escalation framework for flagging deviations from typical daily variability and detecting baseline drift. See the figures below for the full limits.



Global I–MR SPC limits from 567 daily QA records (Mar 2023 – Jan 2026)

Metric	CL (%)	2σ warning (%)	3σ action (%)
Output	0.543	0.421 – 0.666	0.359 – 0.728
Beam-shape constancy	0.335	0.239 – 0.431	0.191 – 0.479
Axial symmetry	0.098	–0.131 – 0.328	–0.247 – 0.444
Transverse symmetry	–0.018	–0.367 – 0.331	–0.543 – 0.507

2σ flags a warning; 3σ triggers action — a standardized escalation framework beyond fixed pass/fail tolerances.

Key findings

- Global I–MR SPC set machine-specific daily QA thresholds from 567 records spanning nearly three years (Mar 2023–Jan 2026).
- Output and beam-shape constancy were tightly controlled (CL 0.543% and 0.335%; narrow 3σ bands), reflecting stable delivery.
- Symmetry metrics centered near zero (axial 0.098%, transverse –0.018%) but had far wider action bands — one fixed tolerance would misflag them.
- The 2σ warning / 3σ action bands give a standardized escalation framework for spotting non-random baseline drift.
- Easy to implement, the method can guide institutional thresholds and periodic baseline review, complementing tolerance-only QA.

Conclusion

- ❑ Global I–MR SPC provides practical, machine-specific 2σ warning and 3σ action levels for MR-Linac Daily QA, complementing tolerance-based QA with standardized trending and earlier identification of performance change.
- ❑ The approach is easy to implement and can guide institutional thresholds and periodic baseline review.

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