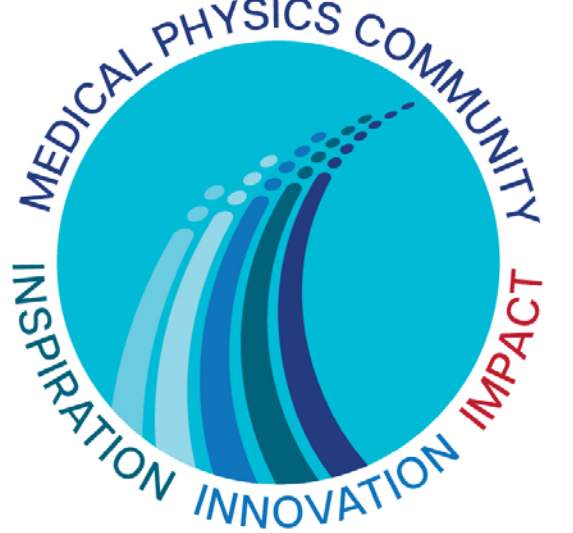




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Longitudinal Trending of MR-Linac Couch Shift Accuracy and Image Registration Consistency

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Objective

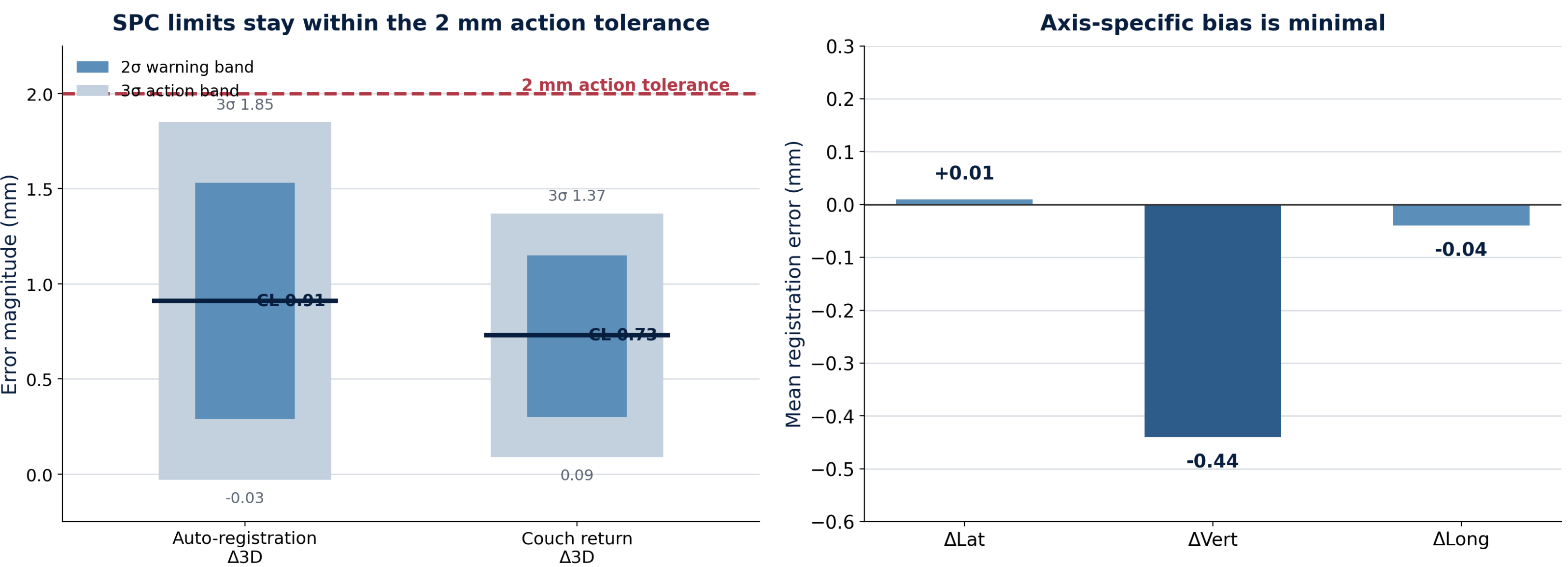
Couch shift accuracy and image-registration performance are central to MR-guided radiotherapy, yet QA is often interpreted with fixed tolerances alone. This study applied statistical process control (SPC) to derive machine-specific 2σ (warning) and 3σ (action) limits for a daily couch alignment/shift test incorporating TRUFI auto-registration, and to provide a framework for detecting baseline shifts, particularly after service or recalibration events..

Methods

- ❑ Daily couch QA records (n=498) from a clinical MR-Linac were retrospectively analyzed. The test used known manual shifts (Lat/Vert/Long = -1/-2/-2 cm) followed by TRUFI auto-registration. Registration accuracy was quantified as Δ = Expected – Reported for each axis and as a 3D magnitude error ($\Delta 3D$).
- ❑ Couch reproducibility was quantified by the 3D difference between the return position and the initial plan-enabled couch coordinates (Return $\Delta 3D$). Individuals–Moving Range (I–MR) control charts were applied.
- ❑ Center lines (CL) were computed as means, with 2σ warning and 3σ action limits calculated as $CL \pm 1.77 \cdot MR$ and $CL \pm 2.66 \cdot MR$, respectively (MR = mean moving range).

Results

Statistical process control on 498 daily QA records produced machine-specific control limits. Auto-registration $\Delta 3D$ had a center line of 0.91 mm (2σ 0.29–1.53 mm; 3σ -0.03–1.85 mm), and couch return $\Delta 3D$ a center line of 0.73 mm (2σ 0.30–1.15 mm; 3σ 0.09–1.37 mm). Axis-specific center lines were near zero (ΔLat 0.01, $\Delta Vert$ -0.44, $\Delta Long$ -0.04 mm), indicating minimal systematic bias. Critically, both 3σ upper action limits stayed below the 2 mm tolerance — see the figures below.



I-MR control limits from 498 daily QA records

Metric	CL (mm)	2σ warning (mm)	3σ action (mm)
Auto-registration Δ3D	0.91	0.29 - 1.53	-0.03 - 1.85
Couch return Δ3D	0.73	0.30 - 1.15	0.09 - 1.37

Both 3σ upper action limits (1.85 mm and 1.37 mm) fall below the 2 mm clinical action tolerance — performance is stable and in control.

Key findings

- SPC on 498 daily QA records set machine-specific limits: auto-registration $\Delta 3D$ center line 0.91 mm; couch return $\Delta 3D$ center line 0.73 mm.
- Both 3σ action limits (1.85 and 1.37 mm) stayed below the 2 mm clinical tolerance — performance is stable and in control.
- Axis-specific registration bias was minimal (ΔLat 0.01, $\Delta Vert$ -0.44, $\Delta Long$ -0.04 mm), with no meaningful systematic offset.
- I–MR control charts enable baseline-shift surveillance after service, recalibration, or software changes.
- The framework transfers to other radiotherapy platforms, advancing beyond tolerance-only QA to longitudinal trending.

Conclusion

- ❑ I–MR SPC provides practical, machine-specific $2\sigma/3\sigma$ warning/action levels for MR-Linac couch shift and TRUFI registration QA, while also enabling baseline-shift surveillance (e.g., sustained CL shifts or increased MR) after maintenance, recalibration, or software changes. The same methodology is readily transferable to other radiotherapy platforms to standardize trending, support post-intervention re-baselining, and strengthen longitudinal performance monitoring beyond tolerance-only QA.

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