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1. BACKGROUND

High dose-rate (HDR) prostate brachytherapy is sensitive to perineal oedema which can displace interstitial needles and dwell positions from their planned positions. At MVCC, corrective action (CA) accounts for this based on a computed tomography (CT) verification scan immediately prior to treatment delivery. The Bravos (Varian Medical Systems, Palo Alto, CA) afterloader treatment console allows direct adjustment of planned dwell positions in each channel. For instances where the first, loaded dwell position is required at the tip of the catheter, a partial re-insertion of the applicator may be required.

CA at MVCC is performed by comparing the needle tip positions on the verification and planning CT images. In the absence of an external alignment reference, each image has a different origin, therefore, determining the needle tip locations and subsequent dwell position shifts in the same coordinate system is reliant on the axial slice value of the tip and the longitudinal (Z) registration distance between the images. Two physicists independently perform this task and must agree on these values.

Following a near geographical miss incident in 2024 attributed to an incorrect sign on the Z-value, a service evaluation was undertaken to quantify CA variability and establish tolerance thresholds to highlight such cases, and to support evidence-based, safer practice.

CORRECTIVE ACTION WORKFLOW

**Planning CT**
Applicators implanted under ultrasound guidance in theatre before patient has CT scan.

**Verification CT**
After planning approval, patient has CT scan immediately prior to treatment delivery

**CA Calculation**
Axial slice value of all needle tip positions and Z registration distance determined by 2 physicists independently

**Treatment Delivery**
Corrected dwell positions applied in treatment console (+ any re-insertions required) and treatment delivered

2. AIM

To quantify corrective action variability and establish evidence-based tolerance thresholds to improve treatment safety.

KEY TAKEAWAYS

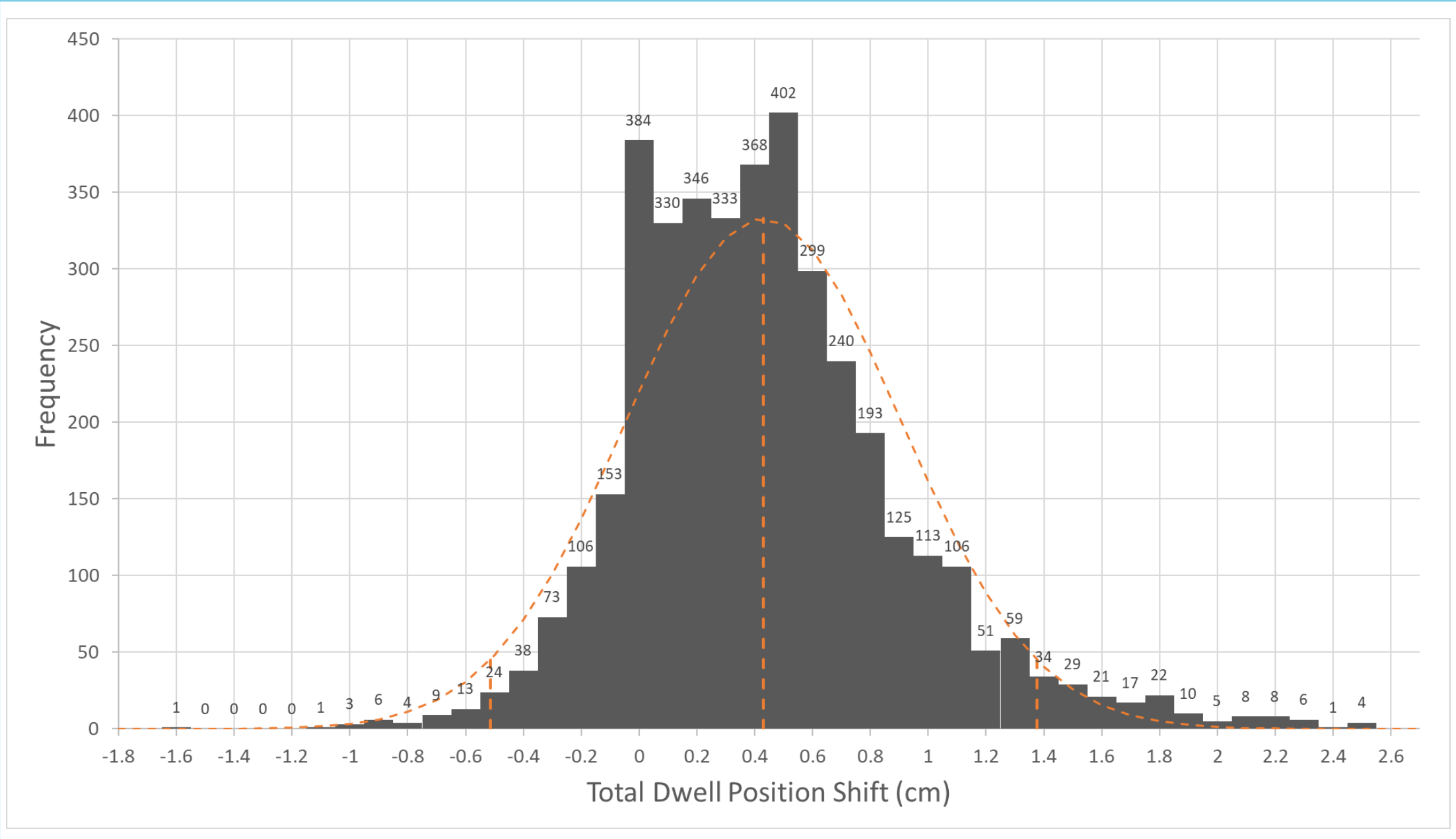
- ✓ Patient CA shifts are approximately normally distributed with a systematic positive bias.
- ✓ A 95% CI tolerance threshold of -0.5 cm to +1.3 cm was established.
- ✓ Day 2 needles show greater shifts than Day 1, consistent with oedema progression and natural disruption from overnight stays
- ✓ The near miss data were >6 SD from the clinical cohort, highlighting the value of tolerance thresholds in identifying outliers.
- ✓ Threshold implementation strengthens verification processes and enhances patient safety.

3. METHODS

-  Clinical, loaded needles (n = 3945) in 2024 retrospectively reviewed. Boost, monotherapy and salvage cases included (172 patients)
-  Total CA shifts recorded (dwell position shifts along needle + physical needle shifts)
-  Data histogram approximately normally distributed; Gaussian function fitted and scaled to data
-  Data categorised into “Day 1” and “Day 2” needles; accounts for data from patients with overnight stay
-  95% confidence interval (CI) determined to establish tolerance thresholds

4. RESULTS – ALL CLINICAL NEEDLES (2024)

Figure 1. Distribution of Total Corrective Action Shifts: Planned vs Corrected First Non-zero Dwell Position Differences + any re-insertion distances

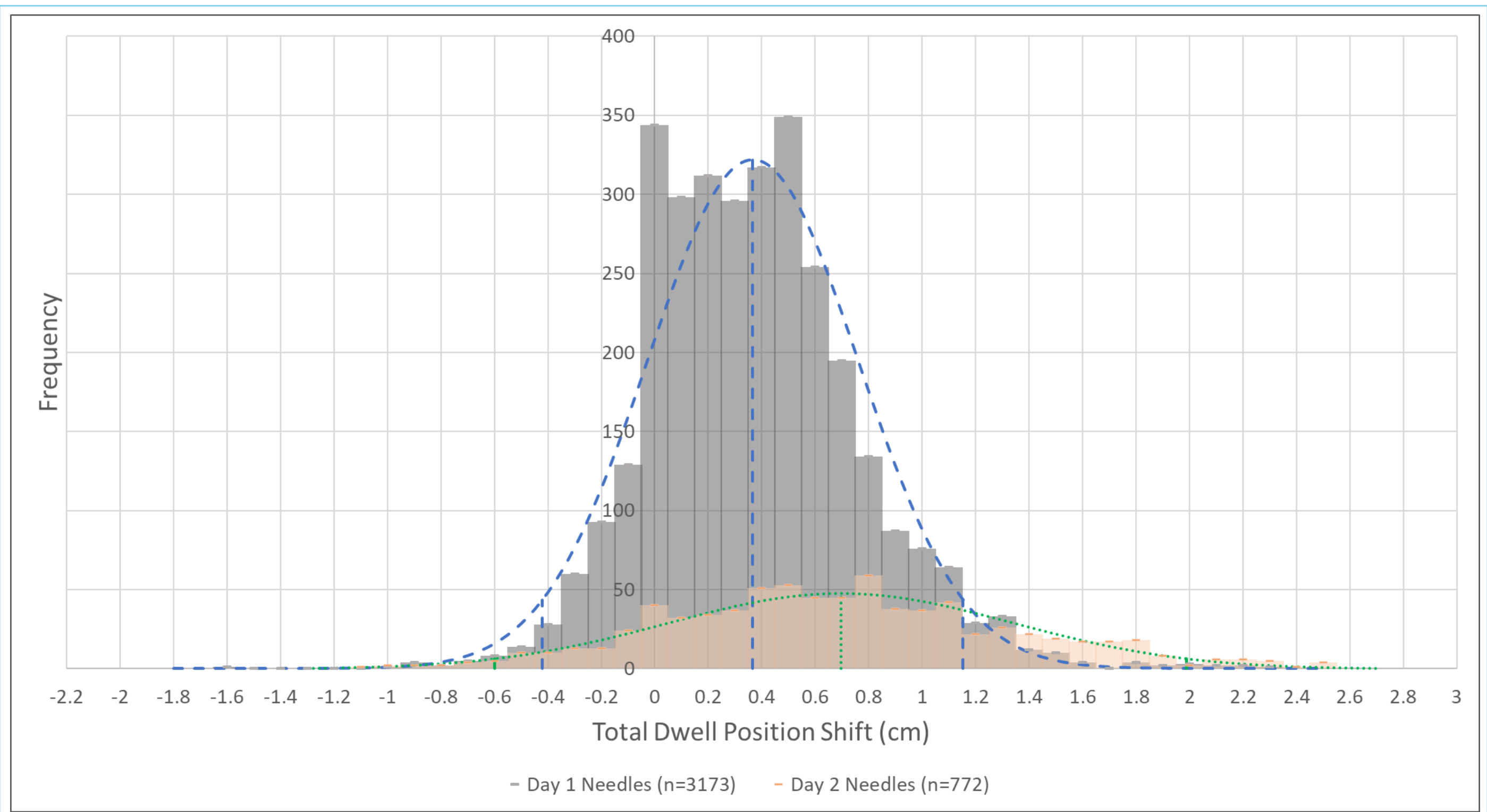


- ~95% of needles required a corrective action between -0.51 cm and +1.38 cm
- Positive values indicated dwell position shifts required towards the needle tip
- Negative values reflected needle migration further into the patient in the time between planning and verification CT images

- Distribution exhibited a positive skew, demonstrating systematic tendency for needle withdrawal relative to planned positions
- This is the expected outcome for HDR prostate brachytherapy implants

5. RESULTS - DAY 1 vs DAY 2 COMPARISON (2024)

Figure 2. Distribution of Total Corrective Action Shifts: Day 1 vs Day 2 Needles



DAY 1 NEEDLES		DAY 2 NEEDLES	
% of total needles	80%	% of total needles	20%
Mean Shift	+0.37 cm	Mean Shift	+0.70 cm
Standard Deviation	0.39 cm	Standard Deviation	0.65 cm
~95% CI	-0.42 cm to +1.15 cm	~95% CI	-0.60 cm to +1.99 cm

- Larger displacement of needles is expected from overnight stays due to oedema progression and patient discomfort
- Greater variability of needle displacements was also expected
- Data showed the magnitude and range of CA was greater on the 2nd day of treatment

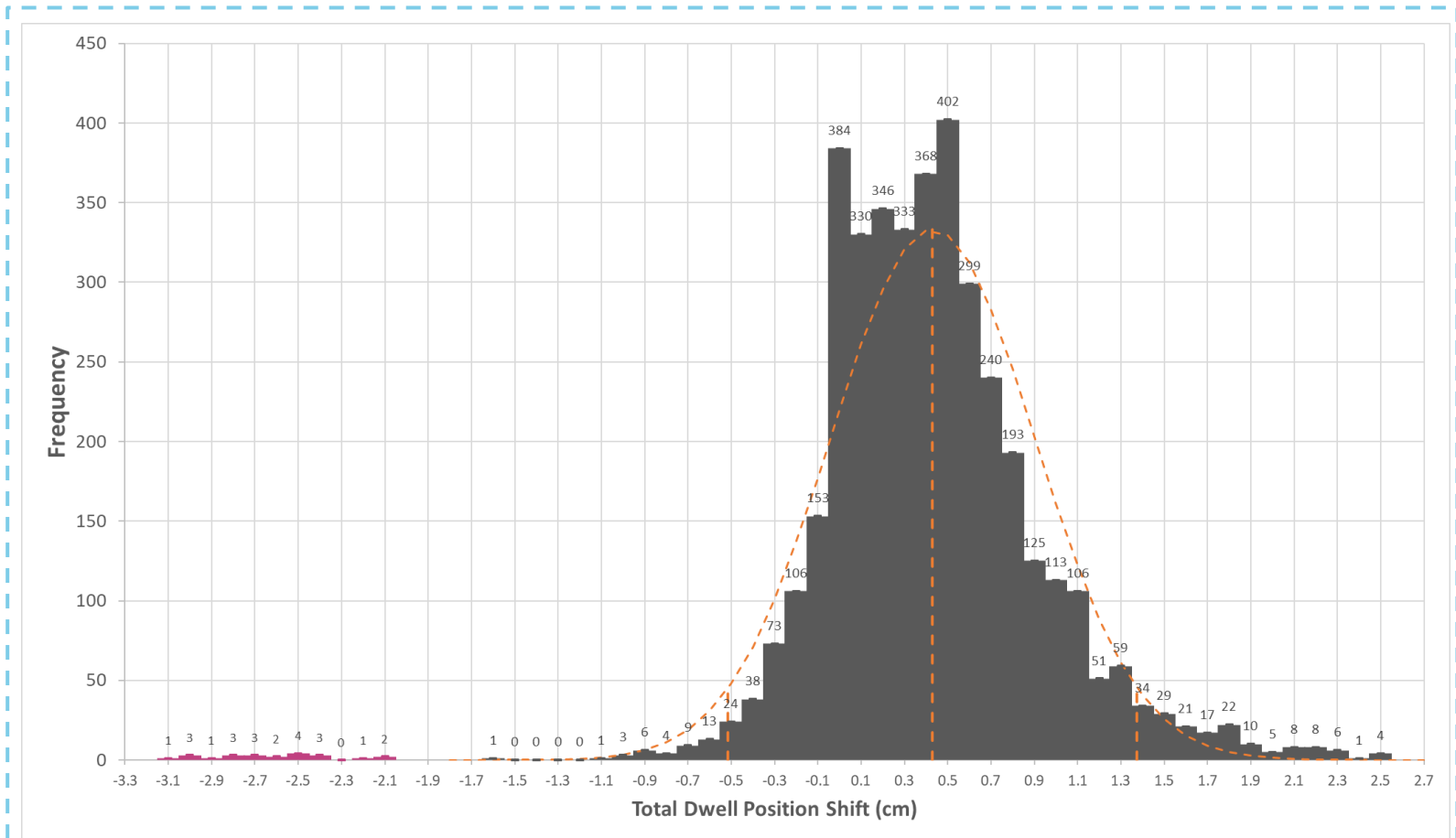
6. 95% CI Tolerance Threshold

A tolerance threshold to highlight suspicious needles, based on the 95% CI, weighted accordingly from the proportion of Day 1 and Day 2 needles, was determined:

-0.5 cm to +1.3 cm

7. NEAR MISS ANALYSIS

Figure 3. Near Miss vs Clinical Cohort CA Data



- Clinical Needles (2024), n = 3945
- Near Miss Case (2024), n = 23

- Near geographical miss: the mean total dwell position shift was >6 standard deviations from the mean of the clinical cohort
- All 23 needles required a negative correction; the mean CA required was -2.6 cm
- Error due to incorrect sign (-Z instead of +Z)
- Caught during the data input stage into the Bravos treatment console
- With the correct sign, the mean CA required was +0.4 cm (range 0 cm to +0.9 cm)

7. CLINICAL IMPACT

-  Evidence-based tolerance threshold established (-0.5 cm to +1.3 cm) from population
-  Outlier CA values can be identified and investigated early
-  Strengthened dual physicist verification process
-  Improved treatment safety and consistency
-  Supports ongoing quality improvement and learning

8. CLINICAL USE OF TOLERANCE THRESHOLD

- Needles naturally retract outward from a patient
- ~95% required the dwell position to be moved back from the tip by <5 mm
- Tolerance thresholds readily identifies outliers:

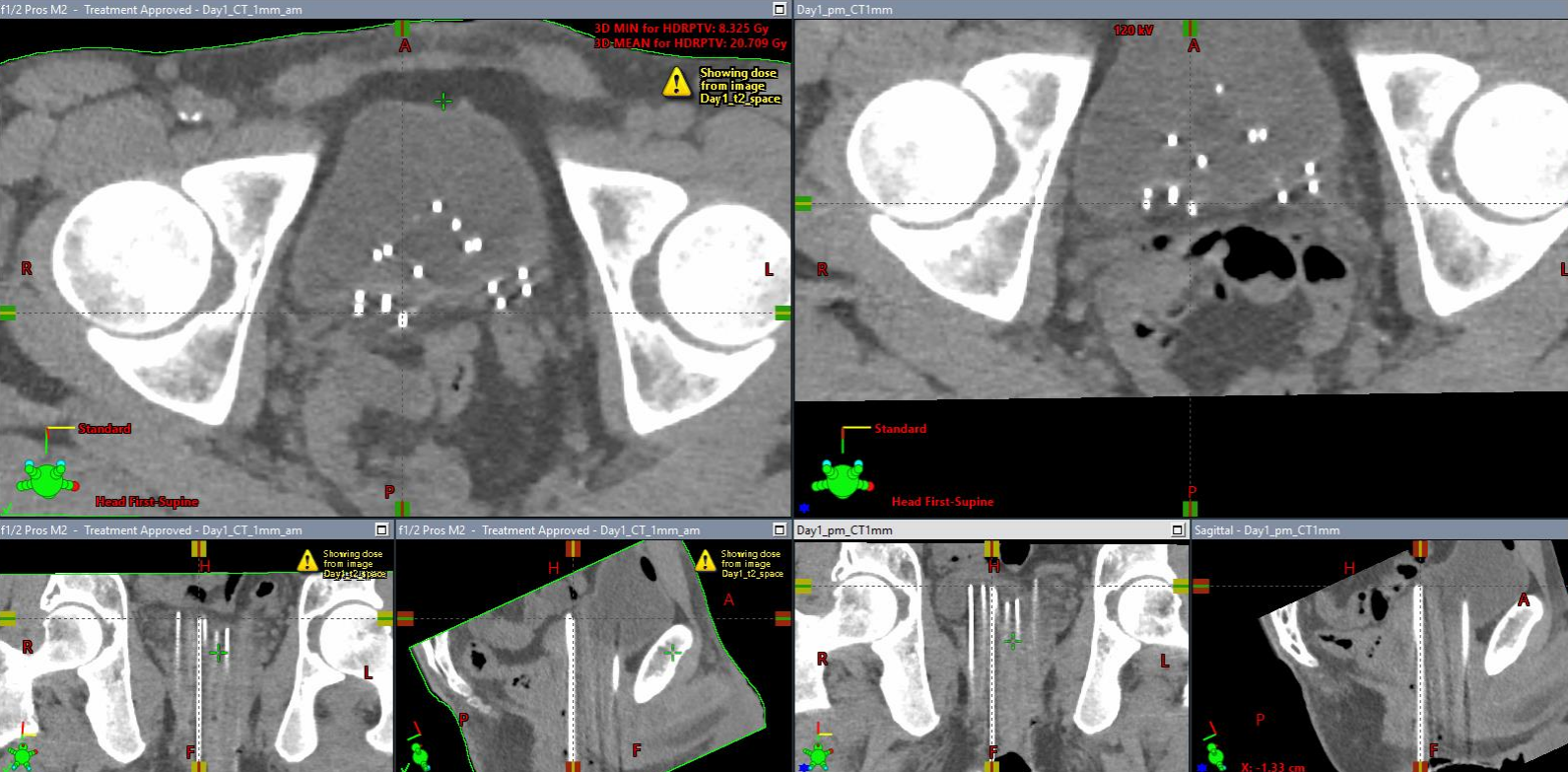


Figure 4: Needle that had migrated into the patient, observed on sagittal and coronal views between planning (LHS) and verification (RHS) images. The dwell position required a -6mm shift. Further review determined this was not an outlier and differences were due to changes of the rectum.

9. CONCLUSION

- Quantitative evaluation of MVCC Corrective Action enabled the development of clinically meaningful tolerance thresholds from a representative sample of the population.
- This supports early identification of outliers, strengthens verification processes and enhances the safety and accuracy of HDR prostate brachytherapy following a near miss incident.

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