Robust Optimization Margins for Proton Therapy Using Clinically Reported Intrafraction Motion on a Proteus™ONE Proton System

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ABSTRACT

INTRODUCTION: Five years of field-by-field couch-shift data recorded by radiation therapists on the ProteusONE™ proton system were analyzed to derive clinically relevant robust-optimization margins and to evaluate the adequacy of existing margin guidance.
METHODS: Site-specific imaging protocol using all available modalities on the ProteusONE™ include intrafraction oblique images whenever the couch is rotated during the first three fractions and weekly thereafter. In prostate and prostate plus regional lymph node cases, imaging preceded each field in all fractions and followed each field for the first ten fractions. Shifts were grouped into four cohorts: masked immobilization, no-mask immobilization, localized prostate, and prostate with pelvic nodes. For each cohort the mean (M), systematic standard deviation (Σ), and random standard deviation (σ) of intrafraction motion were computed. Traditional IMRT planning target volume (PTV) margins were then calculated using both the Van Herk prescription (2.5 Σ + 0.7 σ) and a simple 3σ approach on the mean couch-shift data.
RESULTS: Van Herk margins were 1.22-1.26 mm (mask) and 1.25-1.32 mm (no-mask), with a 3-D aggregate of 1.42 mm and 1.60 mm, respectively. For prostate-only plans the aggregate was 2.78 mm; for prostate-plus-nodes it rose to 3.49 mm. The 3σ method produced consistently larger 3-D aggregates—1.74 mm, 2.04 mm, 3.39 mm, and 4.26 mm—which are 22–28 % greater than the Van Herk estimates. Across all sites the 3σ margins offered a tighter safety buffer, notably in 3-D space, but at the cost of higher normal-tissue exposure. Directional Van Herk margins therefore provide the most robust plans while sparing surrounding tissues.
CONCLUSIONS: The Van Herk prescription yields smaller robust-optimization margins than the 3σ method. Nonetheless, applying 3σ margins directionally can still preserve normal-tissue dose while aligning robust optimization with observed uncertainties.

20 YEARS EST. 2006 UF HEALTH PROTON THERAPY INSTITUTE

INTRODUCTION

AT UFHPTI, the Proteus™ONE system was first used for treatments starting January 2020. **Figure** 1 below is an image of the Proteus™ONE system with on-board Imaging and Oblique X-rays that are imbedded in the floor.

Figure 1: ProteusOne™ Compact Gantry system capable of CBCT, Orthogonal imaging, and oblique imaging.

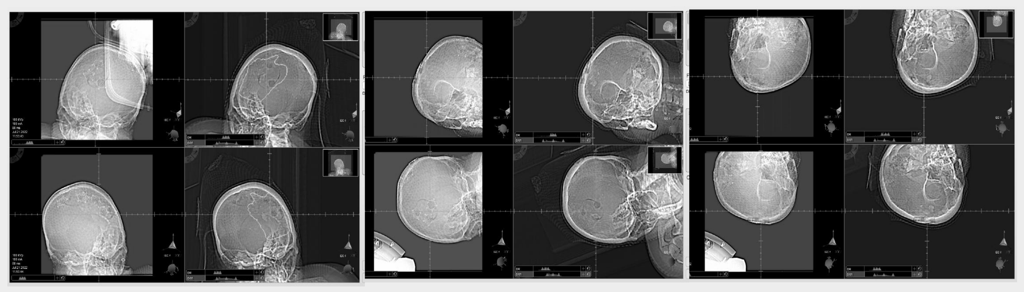

Figure 2: Oblique Imaging on ProteusOne™ for 3 unique Treatment Couch Angles

METHODS

Due to the nature of a compact gantry system the couch is rotated between 0 degrees and 180 degrees in order to treat lateral fields. In order to ensure that this couch rotation doesn't introduce more patient motion, all patients with any couch rotations are imaged using Oblique Images **(Figure 2)** prior to each field of treatment for at least the first several fractions of treatments. Until the Fall of 2024, oblique images shift or intrafraction motion were reported in a spreadsheet. In order to ensure that the couch rotation tracked around isocenter, weekly couch rotation and imaging QA was performed using a rigid phantom **(Figure 3)**. **Figure 4** is an example of a Mask used for immobilizing cranial and head and neck cases.

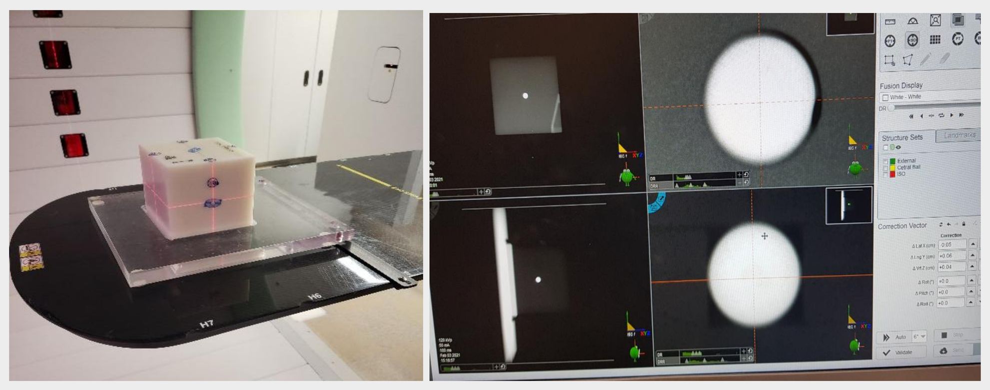

Figure 3: QA Phantom and imaging on the Proteus™ONE system.

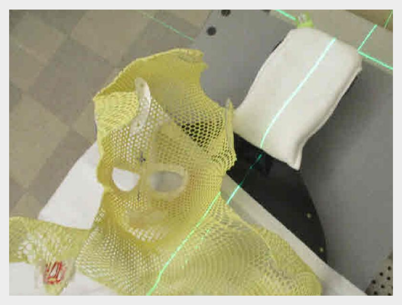

Figure 4: Example of immobilization used for intracranial and Head and Neck cases (indicated as "MASK" in the results section.

RESULTS

Graphs of all data for each disease site both for magnitude of all shifts (Figure 5 LEFT) and for the distributions per axis (Figure 6 RIGHT).

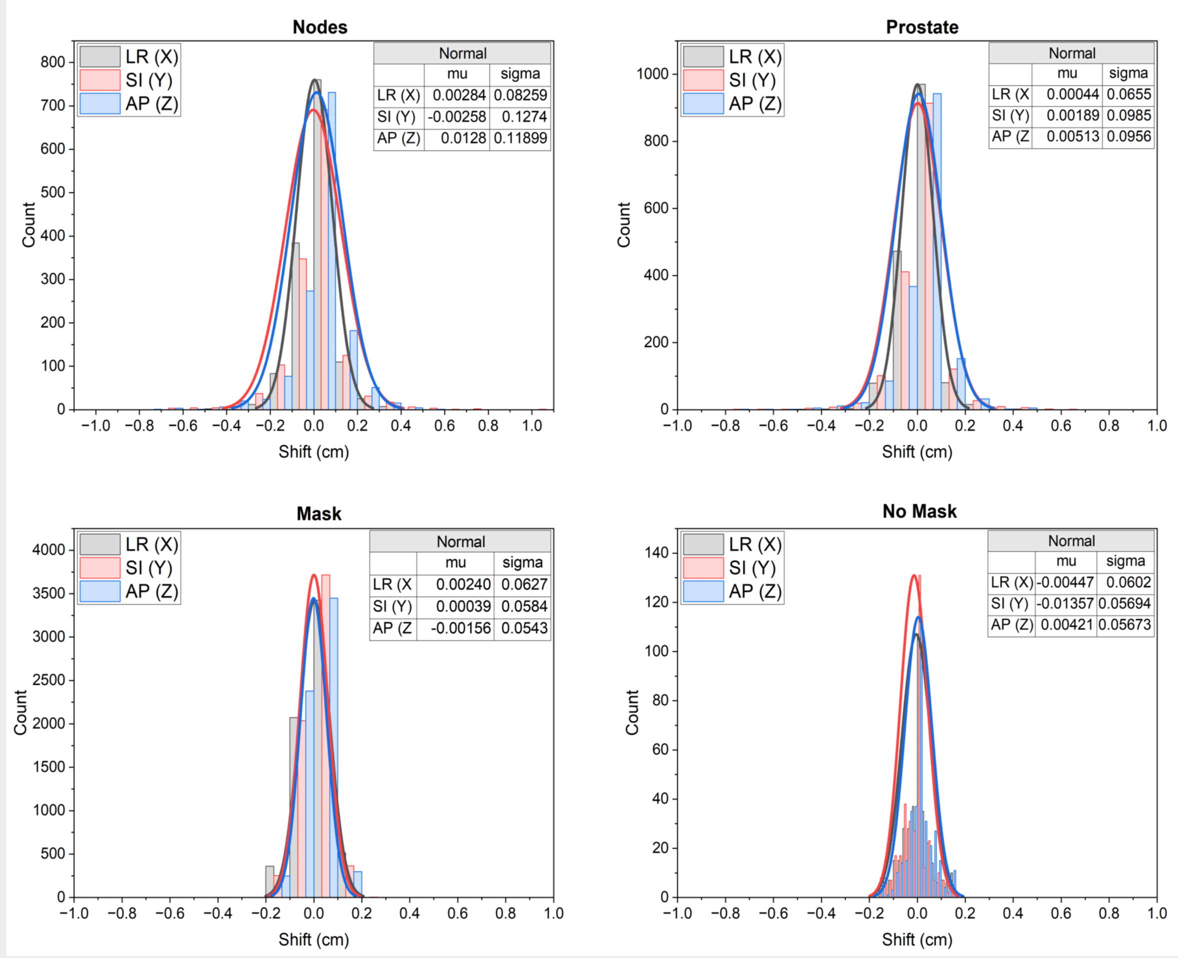

Figure 5: Overall Intrafraction Motion for Different Sites.

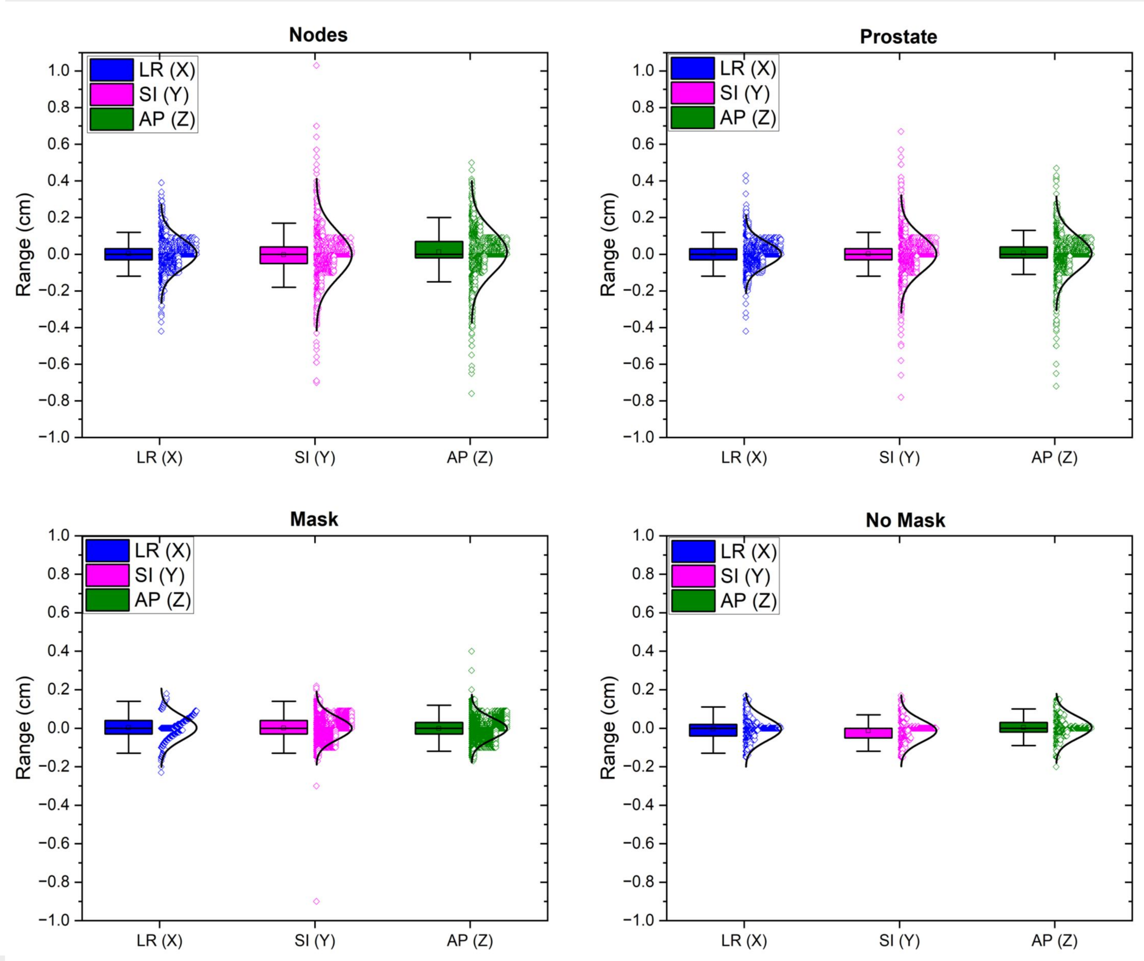

Figure 6: Spread of Directional Shifts for Different cases Note the increase in motion and margin needed for Prostate patients with regional nodes

Proposal of setup margin based on statistical deviations of all intrafraction motion data utilizing the Van Herk Formula and a 3 Sigma of all Couch rotation data is shown in TABLE 1. Note that based on the QA results, there are no conditions that should not have at least a 1mm Uncertainty margin in all directions.

TABLE 1: Recommended Setup Robustness for different sites and directions.

	Margin Formula 2.5∑ + 0.7σ **(mm)**				3σ (for mean of Couch Shift data) **(mm)**			
	X (Lat)	**Y (S/I)**	**Z (A/P)**	**3D**	**X (Lat)**	**Y (S/I)**	**Z (A/P)**	**3D**
QA	0.57	0.66	0.48	0.60	0.98	1.03	0.65	0.81
Mask	1.26	1.22	1.22	1.42	1.26	1.32	1.17	1.74
No Mask	1.25	1.25	1.32	1.60	1.20	1.32	1.23	2.04
Prostate	1.59	2.36	2.34	2.78	1.98	2.97	2.88	3.39
P+Nodes	3.22	4.96	5.19	3.49	2.49	3.81	3.57	4.26

CONCLUSIONS

The Van Herk prescription yields smaller robust-optimization margins in 3D, However, applying 3σ margins directionally can still preserve normal-tissue dose while aligning robust optimization with observed uncertainties. Note the Van Herk formalism gives more conservative (larger motion) for the prostate and Prostate+Nodes due to the inclusion of residual setup variation in this population.

An example of proposed robust optimization settings in Raystation™ for patient setup uncertainty. This proposal uses the largest setting observed in the summary above.

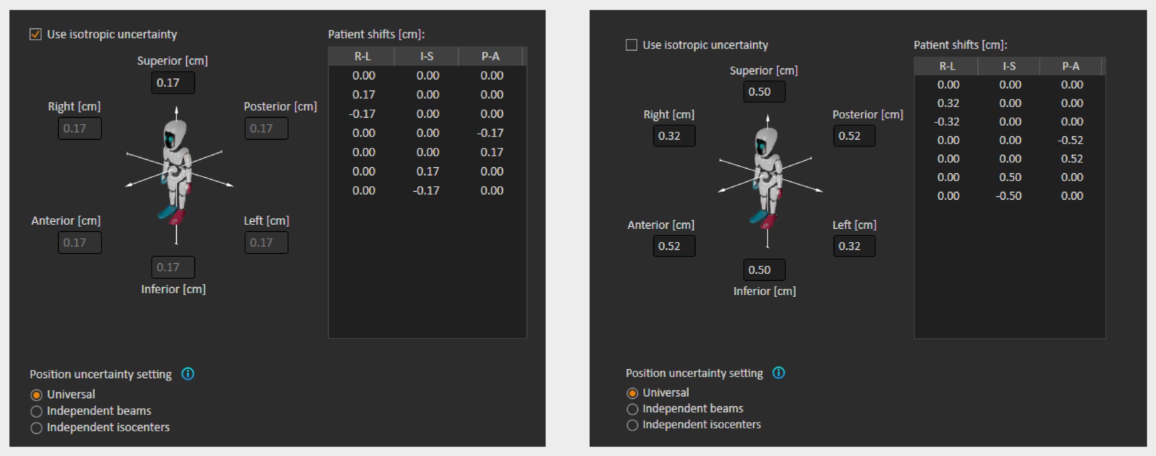

Figure 7: Proposed Robustness settings Mask LEFT and Prostate+NODES Right

DISCUSION

Note that these directional uncertainties do not change the need for beam specific Range Uncertainty based on the institutions guidelines. Additionally, this investigation does not evaluate margins for targets that may have respiratory or cardiac motion uncertainties.

REFERENCES

(1) G. Shafai-Erfani, T. Willoughby, N. Ramakrishna, S. Meeks, P. Kelly, O. Zeidan. Effectiveness of base-of-skull immobilization system in a compact proton therapy system. *J. Appl Clin Med Phys*. **2018**. 19(3): 261-267.

(2) Marcel van Herk Errors and margins in radiotherapy. *Seminars in Radiation Oncology* Vol 14, Issue 1 **2004**, pp. 52-64.

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