

Theme: Clinical

Abstract No: PTCOG-AO2025-ABS-0119

Abstract Title: Dose-LET Volume Histogram Metrics in Breast Cancer Patients Undergoing Proton Therapy: A Single-center Analysis

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Background / Aims:

In breast cancer patients undergoing pencil-beam scanning proton therapy (PBS), increased linear energy transfer (LET) near the end of the proton range may impact adjacent ribs, potentially heightening the risk of fractures. This study summarizes dose-LET volume histogram (DLVH) metrics from PBS treatment plans at our institution, providing a reference range based on clinical outcomes.

Subjects and Methods:

We retrospectively analyzed treatment plans of **109** breast cancer patients (70 left-sided, 36 right-sided, 3 bilateral) treated with PBS between July 2023 and December 2024. Prescription doses included 50 GyRBE in 25 fractions (15%), 40–40.05 GyRBE in 15 fractions (79%), and 25 GyRBE in 5 fractions (6%). Simultaneous integrated boost (SIB) doses for chest wall targets were 57.7–60 GyRBE (56%), 45–48 GyRBE (60%), and 30 GyRBE (86%). All patients underwent single-field optimized (SFO) PBS with two fields, and treatment plans were generated using RayStation v12A & 2024A with robust optimization (setup uncertainty ± 5 mm, range uncertainty $\pm 3\%$). CTV planning goals were $D_{95\%} \geq 95\%$ ($D_{90\%} \geq 90\%$ for internal mammary nodes) under worst-scenario robustness evaluation, and $D_{0.01cc} \leq 110\%$. Ribcage constraints were $V_{50\%} \leq 30cc/D_{0.03cc} \leq 95\%$ of boost dose (primary) and $V_{50\%} \leq 100cc/D_{0.01cc} \leq 105\%$ of boost dose (acceptable). DLVH indices, $V(D, L)$, representing ribcage volume with at least dose (D) and dose-averaged LET (L), were extracted from RayStation LET distributions; $V(50\text{--}60\%$ of prescription dose, 4–6 keV/ μm) was analyzed.

Result:

Thirty-five percent of patients received lymph node irradiation, with mean ribcage volume of 460cc (range: 309.7–597.4cc). All plans met clinical target goals. Regarding the ribcage, none achieved $V_{50\%} \leq 30cc$, while 79% met $V_{50\%} \leq 100cc$. $D_{0.03cc} \leq 95\%$ was met in 27%, and $D_{0.01cc} \leq 105\%$ in 90%. As shown in Table 1, mean values of $V(50\%, 6 \text{ keV}/\mu m)$ and $V(60\%, 6 \text{ keV}/\mu m)$ were $10.6 \pm 2.2\%$ and $8.2 \pm 2.0\%$, respectively. Three outliers were identified for $V(50\text{--}60\%, 6 \text{ keV}/\mu m)$ based on exceeding the **upper limit of the 95% confidence interval ($>14.9\%$ for $V(50\%, 6 \text{ keV}/\mu m)$ and $>12.0\%$ for $V(60\%, 6 \text{ keV}/\mu m)$** , differing from those flagged by other indexes. Median follow-up was 142 days (range: 10–794); no rib fractures were reported, but seven patients (median follow-up: 240 days) experienced grade 1 chest wall pain, **two coinciding with outlier cases**.

	V(50%, 6keV/ μ m)	V(50%, 5keV/ μ m)	V(50%, 4keV/ μ m)	V(60%, 6keV/ μ m)	V(60%, 5keV/ μ m)	V(60%, 4keV/ μ m)
Mean	10.6%	14.4%	16.7%	8.2%	11.7%	13.9%
SD	2.2%	3.0%	4.3%	1.9%	2.7%	4.0%
Lower (-1.96SD)	6.3%	8.5%	8.4%	4.4%	6.4%	6.2%
Upper (+1.96SD)	14.9%	20.3%	25.1%	12.0%	17.0%	21.7%
Range	4.6%-15.5%	6.6%-21.8%	7.1%-26.9%	3.2%-12.7%	4.9%-17.6%	5.5%-24.6%

Table 1. Summary of dose-LET volume histogram (DLVH) metrics from treatment plans at our institution.

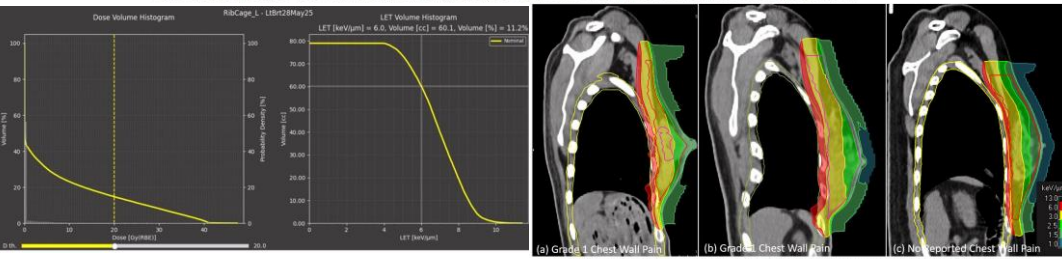


Figure 1. Demonstration of dose-LET volume histogram (DLVH) metrics. (RayStation script contributed by **Giuseppe Magro, PhD, CNAO Foundation**)