

Is There a Clinical Benefit with a Smooth Compensator Design Compared to a Plunged Compensator Design for Passively Scattered Protons?

A.Tabibian¹; A.Powers¹; K.Dolormente¹; S.Oommen¹; A.Tiwari¹; M.Palmer, MBA, CMD²; X.R.Zhu, PhD³; H.Li, PhD³; N.Sahoo, PhD³; P.Wisdom³; K.Velasco, CMD, RT(T)⁴; K.Erhart, PhD⁵; H.Stanley, BS⁵; B.T.Nguyen, BS, CMD²

¹ University of Texas School of Allied Health- Medical Dosimetry, Houston, TX; ² MD Anderson Department of Radiation Oncology, Houston, TX; ³ MD Anderson Department of Radiation Physics, Houston, TX; ⁴ Radiation Oncology Resources, Goshen, IN; ⁵ Decimal, Inc, Sanford, FL

Purpose/Objectives

The purpose of this study was to investigate the potential dosimetric and milling time benefits of smooth compensators

Learning Objectives:

- 1) Understand the purpose of a compensator in passive scattered protons
- 2) Outline the uncertainties with plunged-depth compensators
- 3) Investigate the potential benefits of using smooth compensators

Introduction

Proton therapy has the ability to deposit the maximum dose per beam in the target at a defined depth with its Bragg Peak. ¹ This gives protons the ability to preserve healthy tissues distal to the target. The distal dose conformity is aided by a wax or acrylic compensator for passively scattered proton therapy.^{2,3}

The most common manufacturing design for compensators is a "plunged" technique. The plunged technique mills the compensator through a series of points, one-by-one to a specific depth with a drill bit of a specified diameter, usually 2-5mm, and taper angle, usually 2-3 degrees. A high resolution design is optimal, but the thickness of the drill bit degrades the degree of resolution of the compensator design and resultant dose distribution on the distal end of the target.^{6,7} In addition, this technique can be very time consuming because the compensator design is very complicated and involves hundreds of plunge points. Clinical effectiveness and patient start times can be affected by the time requirements of the plunge technique.

Alternatively, a "smooth" compensator design is available in the TPS. The plunged-depth points must be converted into a three dimensional wireframe surface so that the compensator can be milled with a smooth surface. There are a few limitations one must consider before clinical implementation of smooth compensators. Access to conversion software that can convert the TPS output into a readable format by the CNC Mill and an engineer with knowledge about how to setup the CNC Mill with the correct tools to mill the smooth compensator is needed for this technique. The smooth compensator design marginalizes steep depth gradients, reduces the distal dose resolution issues related to the drill bit size, and eliminates drill bit tapering issues in the TPS algorithm.

Methods and Materials

Five patients from five different clinical sites, prostate, lung, liver, brain, and CSI, were selected for this study. The patients were randomly selected within each site in order to give the study a broad analysis and distribution of various anatomical sites.

Four smooth compensator plans were designed and compared to the original plunged depth plan. The "Smooth Base" plan is a copy of the original plunged depth plan with the same parameters, but the compensator milling design was changed to smooth. The three additional smooth compensator plans were Double Smear (DS), PTV +1cm, and Manual Edits (ME). The DS plan had doubled the calculated smear value with all other parameters unchanged. The PTV +1cm plan added an additional 1cm to the PTV which was used for the compensator design only. The ME plan was individually assessed and the treatment planner made manual adjustments to the compensator to increase the dose to the areas of the CTV lacking coverage. The plans made sure to have the minimum amount of PTV coverage as the original plunged depth plan in order for the plans to be comparable.

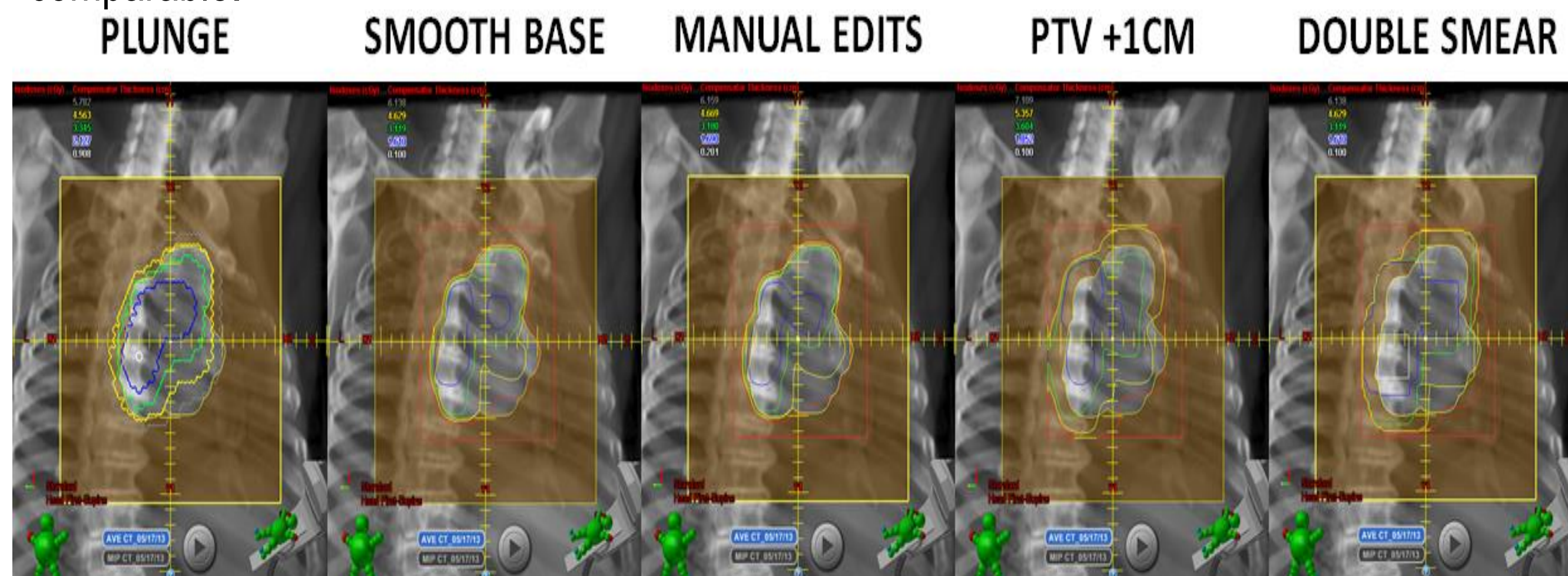


Figure 1. Compensator designs for each smooth compensator technique for a lung patient.

Multi-criteria (MCA) plan quality metrics was used for plan assessment and comparison. Each criterion was given a metric score in proportion to its priority. The metric values for all criterions totaled a maximum score of 150. The parameter ranges were based on the range of dosimetric results from the plunged-depth plans for each criterion rather than clinical constraints so that metric results would be meaningful with small differences between the plans

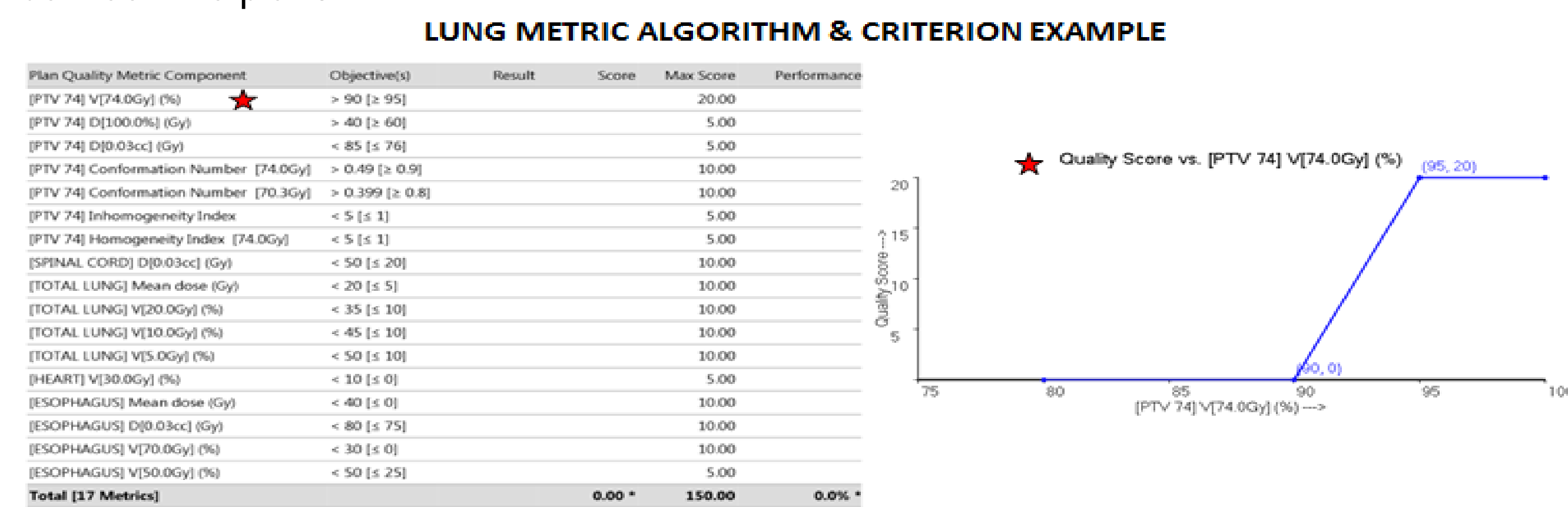


Figure 2. Multi-criteria algorithm for a particular lung case with a criterion range for the PTV coverage.

Results

Dosimetric Results:

In comparison to the plunged-depth plan, the ME plan had similar or better results for all five sites. (Table 1) On average for all five sites, the ME plans performed better than the other smooth compensator techniques.

	Scoring Metric Range	Max Points	Priority	Plunge SB ME PTV+1 DS				
				Plunge	SB	ME	PTV+1	DS
BRAIN								
[D[0.03cc] V[50.4] (%)	≤ 50 [< 56]	5	3%	53.8	1.9	0.1	1.0	1.0
[D[100.0%] V[50.4] (%)	≥ 100 [> 80]	20	13%	93.2	-5.0*	0.5	1.8	-1.8*
[D[100.0%] V[100.0%] (%)	≥ 50.4 [> 40]	5	3%	39.1	-2.1	1.2	4.7	2.7
[Conformation Number [100%] V[0.499] (%)	> 0.499	10	7%	0.64	-	-	-	-0.02*
[Conformation Number [95%] V[0.399] (%)	> 0.399	10	7%	0.54	-0.03*	-	-	-
[Inhomo. Index V[0.5] (%)	< 0.5	5	3%	0.29	0.1	-	-0.1	-
[Homog. Index [100%] V[0.5] (%)	< 0.5	5	3%	0.10	-	-	0.0	-
[PTV 50.4 CGE]								
[OPTIC CHIASM] D[0.03cc] (%)	≤ 0 [< 54]	15	10%	30.7	0.2	0.2	0.2	-0.1
[BRAINSTEM] D[0.03cc] (%)	≤ 0 [< 54]	15	10%	31.2	0.1	0.1	0.2	-0.1
[RT OPTIC NERVE] D[0.03cc] (%)	≤ 0 [< 54]	15	10%	20.4	-1.1	0.3	2.6	0.7
[LT OPTIC NERVE] D[0.03cc] (%)	≤ 0 [< 54]	15	10%	29.4	-0.2	0.1	0.2	0.2
[SPINAL CORD] D[0.03cc] (%)	≤ 0 [< 10]	15	10%	0.1	-	-	-0.1	-
[BRAIN] V[30.0] (%)	≤ 0 [< 30]	10	7%	10.8	-0.9*	-0.6	0.4	0.4
[BRAIN] Mean	≤ 0 [< 15]	5	3%	7.4	-0.4	-0.2	0.2	0.2
LUNG								
[D[0.03cc] V[74.0] (%)	≤ 76 [< 85]	5	3%	83.4	2.9	1.3	1.9	1.1
[D[100.0%] V[74.0] (%)	≥ 95 [> 90]	20	13%	94.9	-2.3*	1.1*	-1.8	-0.9
[D[100.0%] V[100.0%] (%)	≥ 60 [> 40]	5	3%	49.7	-3.1	0.3	9.1	1.5
[Conformation Number [100%] V[0.499] (%)	> 0.499	10	7%	0.70	-0.02*	-	-	-0.04*
[Conformation Number [95%] V[0.399] (%)	> 0.399	10	7%	0.62	-0.02*	-	-	-0.03*
[Inhomo. Index V[0.5] (%)	< 0.5	5	3%	0.44	-0.1*	-	-	-0.1
[Homog. Index [100%] V[0.5] (%)	< 0.5	5	3%	0.17	-0.2*	-0.01*	-	-
[PTV 74 CGE]								
[SPINAL CORD] D[0.03cc] (%)	≤ 20 [< 50]	10	7%	34.5	-0.8	-0.5	0.4	1.0
[TOTAL LUNG] Mean	≤ 5 [< 20]	10	7%	14.1	-0.7*	-0.5*	-0.3	0.6*
[TOTAL LUNG] V[20.0] (%)	≤ 10 [< 35]	10	7%	25.1	-1.6*	-1.0	-0.9	1.2*
[TOTAL LUNG] V[10.0] (%)	≤ 10 [< 45]	10	7%	30.1	-1.4*	-1.0*	-0.3	1.4*
[TOTAL LUNG] V[5.0] (%)	≤ 10 [< 50]	10	7%	32.9	-1.7*	-1.2*	-0.4	1.7*
[HEART] V[30.0Gy] (%)	≤ 0 [< 10]	5	3%	5.8	-1.6	-1.4	-1.7	0.9
[ESOPHAGUS] Mean	≤ 0 [< 40]	10	7%	22.9	-3.0	-2.5	-2.9	1.7*
[ESOPHAGUS] D[0.03cc] (%)	≤ 75 [< 80]	10	7%	62.5	0.9	0.7	1.9	2.3*
[ESOPHAGUS] V[70.0] (%)	≤ 0 [< 30]	10	7%	13.4	-2.3	-1.9	-2.2	2.3*
[ESOPHAGUS] V[50.0] (%)	≤ 25 [< 50]	5	3%	25.2	-5.2	-4.5	-3.3	3.0*
PROSTATE								
[D[0.03cc] V[78.0] (%)	≤ 85.8 [< 89.70]	10	7%	83.5	0.2	n/a	-	-0.9*
[D[100.0%] V[78.0] (%)	≥ 100 [> 98]	30	20%	98.8	-0.2	n/a	0.7	0.3
[D[100.0%] V[100.0%] (%)	≥ 78 [> 74]	30	20%	76.4	-0.6	n/a	0.6*	0.3
[Conformation Number [100%] V[0.499] (%)	> 0.499	10	7%	0.69	0.03*	n/a	-0.1*	-0.1*
[Conformation Number [95%] V[0.399] (%)	> 0.399	10	7%	0.55	0.02*	n/a	-0.1*	-0.1*
[Inhomo. Index V[0.5] (%)	< 0.5	5	3%	0.09	-	n/a	-	-0.02*
[Homog. Index [100%] V[0.5] (%)	< 0.5	5	3%	0.07	-	n/a	-	-0.02*
[PTV 78CGE]								
[RECTUM] V[80.0Gy] (%)	≤ 0 [< 3]	5	3%	1.6	0.1	n/a	0.4	-0.5
[RECTUM] V[75.0Gy] (%)	≤ 0 [< 10]	5	3%	6.8	-	n/a	0.2	0.4*
[RECTUM] V[70.0Gy] (%)	≤ 7 [< 13]	10	7%	10.6	-	n/a	-	0.4*
[RECTUM] D[0.03cc] (%)	≤ 80 [< 85]	5	3%	81.9	-0.1	n/a	0.1	-0.6
[ANT. RECT WALL] V[70.0] (%)	≤ 25 [< 40]	10	7%	32.7	-	n/a	-	1.1*
[FEMORAL HEADS] V[45.0] (%)	≤ 36 [< 40]	5	3%	0.0	-	n/a	-	-
[BLADDER] V[70.0] (%)	≤ 0 [< 20]	10	7%	10.6	-0.2	n/a	1.1	1.0
LIVER								
[D[0.03cc] V[67.5] (%)	≤ 70 [< 76]	5	3%	73.6	1.3*	0.9	1.4*	-0.1
[D[100.0%] V[67.5] (%)	≥ 100 [> 80]	20	13%	88.7	-0.9	0.6	1.7*	0.5
[D[100.0%] V[100.0%] (%)	≥ 60.8 [> 35]	10	7%	42.3	-0.6	0.2	0.4	0.3
[Conformation Number [100%] V[0.499] (%)	> 0.499	10	7%	0.73	-	-	-	-0.05*
[Inhomo. Index V[0.5] (%)	< 0.399	5	3%	0.46	-	-	-	-
[Homog. Index [100%] V[0.5] (%)	< 0.5	5	3%	0.27	0.3*	-	-	-
[PTV 67.5 CGE]								
[LIVER - GTV] Mean	≤ 10 [< 30]	15	10%	20.8	-0.1*	-0.7	1.7	1.0
[LIVER - GTV] V[30.0] (%)	≤ 15 [< 45]	15	10%	30.9	-1.5*	-1.3	2.3	1.7
[SPINAL CORD] D[0.03cc] (%)	≤ 25 [< 50]	15	10%	27.3	-1.2	-1.8	2.1	1.2
[RT KIDNEY] V[14.0] (%)	≤ 0 [< 30]	15	10%	15.0	-0.6	-0.3	1.7	0.4
[LT KIDNEY] V[14.0] (%)	≤ 0 [< 30]	15	10%	4.1	-	-	-	-
[HEART] D[0.03cc] (%)	≤ 0 [< 45]	10	7%	41.9	-3.8	2.7	-0.5	6.5
[HEART] V[40.0] (%)	≤ 0 [< 5]	10	7%	1.6	-0.2	-0.2	0.6	0.5
CRANIOSPINAL								
[D[0.03cc] V[36.0 CGE] (%)	≤ 36 [< 39]	15	10%	41.5	0.6	0.2	0.7	0.1
[D[100.0%] V[36.0 CGE] (%)	≥ 100 [> 90]	45	30%	93.1	-2.5	0.8	-1.7	-2.4*
[D[100.0%] V[100.0%] (%)	≥ 100 [> 95]	45	30%	27.0	2.1	2.8	2.6	2.9
[Conformation Number [100%] V[0.499] (%)	> 0.499	15	10%	0.2	-0.01*	-	-	-
[Conformation Number [95%] V[0.399] (%)	> 0.399	15	10%	0.1	-	-	-	-
[Inhomo. Index V[0.5] (%)	< 0.5	7.5	5%	0.4	-	-	-	-
[Homog. Index [100%] V[0.5] (%)	< 0.5	7.5	5%	0.1	0.02*	0.0	0.02*	0.01*
[SPINAL CORD] V[38.5] (%)	< 50.40	0	0%	1.5	3.8	2.0	3.1	2.2

Statistical Significance (p-value < 0.05): *Plung Depth Plan, *Smooth Compensator Plan

Table 1. The following table displays the dosimetric results for each plan relative to the plunge depth plan. The values for the smooth compensator plans are the absolute differences from the plunge depth result. The point value and priority of each criterion is listed out of a total 150 points.

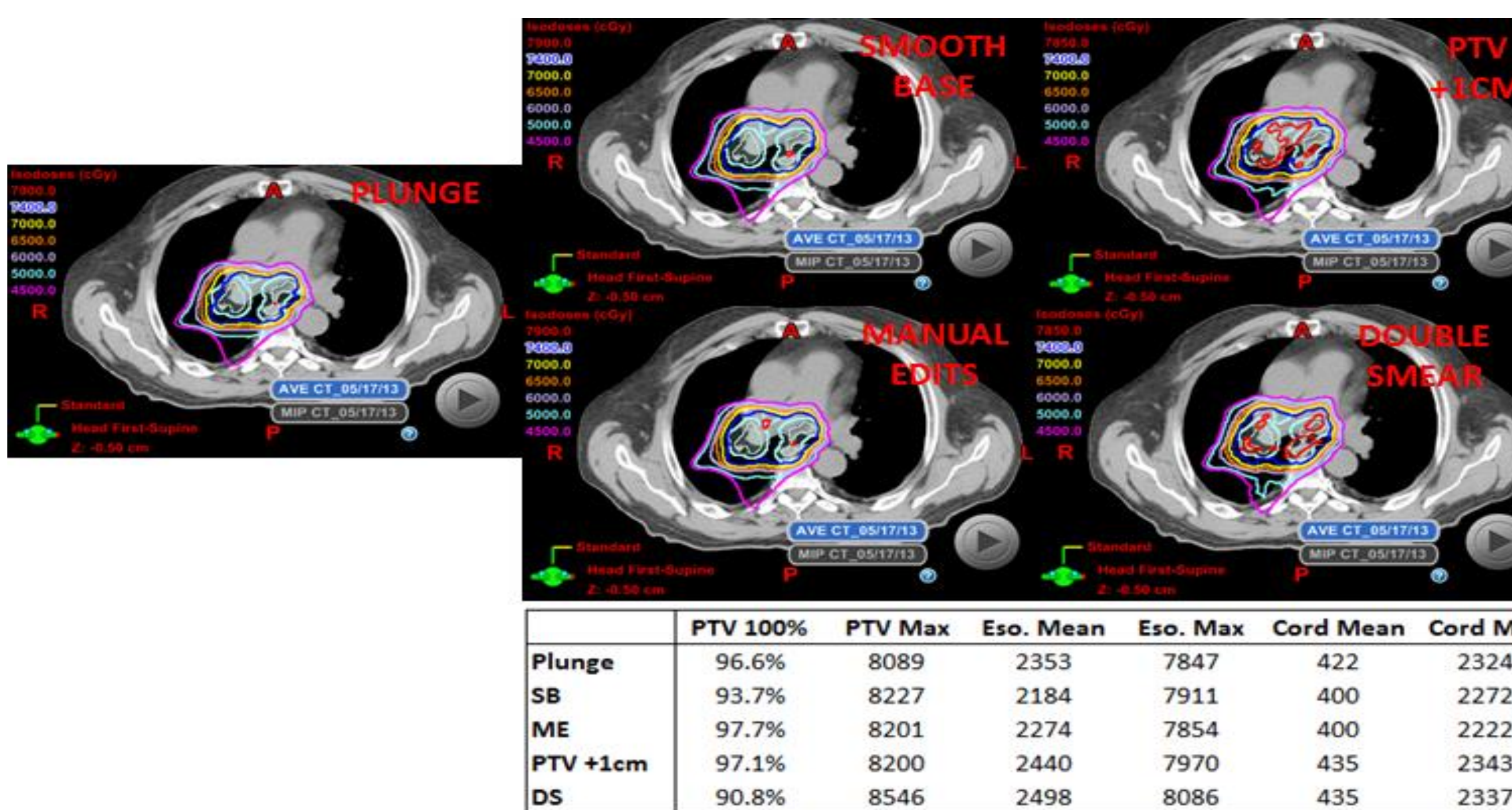


Figure 3. Slice comparison with dose parameters for each technique for a lung plan. The ME plan resulted in better coverage and sparing of the esophagus and cord.

Metric and Performance Results:

Table 2 compares the plan metric and performance results for each smooth compensator technique compared to the plunged-depth plans. The only technique with an increase in the metric and performance results for all five sites was the ME technique with an average metric and performance improvement of +3.0 and +2.0%, respectively.

Results (continued)

	METRIC RESULT					METRIC PERFORMANCE RESULT						
	Plunge	SB	ME	PTV+1	DS	AVG.	Plunge	SB	ME	PTV+1	DS	AVG.
BRAIN	88.1	83.4	89.4	87.3	84.9	86.6	58.7%	55.6%	59.6%	58.2%	56.6%	57.7%
Abs Diff.	-4.7	1.3	-0.8	-3.2	-1.9	-	-3.1%	0.9%	-0.5%	-2.1%	-1.2%	-
LUNG	83.9	81.5	89.4	83.4	72.2	82.1	55.9%	54.3%	59.6%	55.6%	48.1%	54.7%
Abs Diff.	-2.4	5.5	-0.5	-11.7	-2.3	-	-1.6%	3.7%	-0.3%			