Medical Dosimetry 40 (2015) 37–43

Medical Dosimetry

journal homepage: www.meddos.org

# Is there a clinical benefit with a smooth compensator design compared with a plunged compensator design for passive scattered protons?

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A R T I C L E I N F O

*Article history:*
Received 30 April 2014
Accepted 30 July 2014

*Keywords:*
Proton
Smooth compensator
Plunged-depth compensator
Plunge-drilled
Smooth-milled
Passive scattered proton
Compensator

A B S T R A C T

In proton therapy, passive scattered proton plans use compensators to conform the dose to the distal surface of the planning volume. These devices are custom made from acrylic or wax for each treatment field using either a plunge-drilled or smooth-milled compensator design. The purpose of this study was to investigate if there is a clinical benefit of generating passive scattered proton radiation treatment plans with the smooth compensator design. We generated 4 plans with different techniques using the smooth compensators. We chose 5 sites and 5 patients for each site for the range of dosimetric effects to show adequate sample. The plans were compared and evaluated using multicriteria (MCA) plan quality metrics for plan assessment and comparison using the Quality Reports [EMR] technology by Canis Lupus LLC. The average absolute difference for dosimetric metrics from the plunged-depth plan ranged from −4.7 to +3.0 and the average absolute performance results ranged from −6.6% to +3%. The manually edited smooth compensator plan yielded the best dosimetric metric, +3.0, and performance, + 3.0% compared to the plunged-depth plan. It was also superior to the other smooth compensator plans. Our results indicate that there are multiple approaches to achieve plans with smooth compensators similar to the plunged-depth plans. The smooth compensators with manual compensator edits yielded equal or better target coverage and normal tissue (NT) doses compared with the other smooth compensator techniques. Further studies are under investigation to evaluate the robustness of the smooth compensator design.



## 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 conformality is aided by a wax or acrylic compensator for passively scattered proton therapy.[2,3] The design of the compensator is created by a ray-tracing algorithm in the treatment planning system (TPS) that calculates the water-equivalent thickness of proton ray lines from the patient surface to the distal surface of the target.[4] Each beam has a unique compensator because the tumor shape and water-equivalent thickness between the patient surface and distal end of the target are unique, depending on the angle of incidence.

The compensators are designed according to the specifications provided by the TPS and manufactured with a Computer Numerical Control (CNC). The most common manufacturing design for compensators is a "plunged" technique. The plunged technique drills the compensator through a series of points, one by one to a specific depth with a drill bit of a specified tip diameter, usually 2 to 5 mm, and taper angle, usually 2° to 3°. A high-resolution design is optimal, but the diameter of the drill bit limits the degree of resolution of the compensator design and resultant dose distribution on the distal end of the target.[5,6] In addition, this technique can be very time consuming because the compensator design is very complicated and involves hundreds or thousands of plunge points, making it very challenging to apply to the plunge-drilled RC devices because of the complexity of the device surface. Clinical effectiveness and patient start times can be affected by the time requirements of the plunge technique.

The distal dose deposition is dependent on the amount of material in the compensator that the protons pass through at any

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http://dx.doi.org/10.1016/j.meddos.2014.07.004
0958-3947/

point in the compensator. Therefore, it is critically important to ensure that compensators are manufactured correctly as planned.[4] Significant changes in densities in the path of the beam or irregular target shapes can create irregular compensator designs, such as steep gradients, thus introducing more potential uncertainties. Daily misalignment of the patient, tumor motion, and repositioning uncertainties can worsen the effect connected to these gradients because there is uncertainty in the alignment of the (compensator) with the heterogeneities for which it is compensating. Smearing, a thinning operation that extends the thin portion of the original compensator to neighboring regions to account for internal motion of the target and setup uncertainty, is applied in an attempt to improve the probability that the target is covered adequately when these uncertainties are introduced.[7]

It is also important to note that the drill bit tapering is not modeled by the TPS compensator design algorithm, which can increase uncertainties, especially in sharp–depth gradient regions.[4,8] This error does not cause a large dose deviation in regions of small thickness change, but it is a known source of systematic error.[5] The tapering effect is more pronounced for deeper compensators because more material is removed than accounted for in the compensator design pattern. Ultimately, lack of a true drill bit model could result in calculated and measured dose discrepancies.[4,5,8]

Alternatively, a “smooth” compensator design is available in the TPS. The plunged-depth points must be converted into a 3-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 set up the CNC Mill with the correct tools to mill the smooth compensator are 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. The purpose of this study was to investigate the potential dosimetric and milling time benefits of smooth compensators.

## Methods and Materials

### *Patient population*

We selected 5 patients from 5 different clinical sites, prostate, lung, liver, brain, and craniospinal irradiation (CSI), for this study. The patients were randomly selected within each site to give the study a broad analysis and distribution of various anatomical sites.

### *Planning techniques*

The reference plans were the clinically designed passive scattered treatment plans with the plunge technique in Eclipse v9.8 (Varian Medical Systems, Palo Alto, CA). Proximal and distal margins were calculated based on the nominal range and spread-out Bragg Peak (SOBP) of the target for each beam. The proximal and distal margins included a 3.5% computed tomography (CT) number to relative stopping power conversion uncertainty and a 3-mm range uncertainty.[9,10]

$$\text{Proximal margin} = [(3.5\% \times \{\text{range}-\text{SOBP}\}) + \text{range uncertainty (RU)}] \quad (1)$$

$$\text{Distal margin} = [(3.5\% \times \text{range}) + \text{range uncertainty (RU)}] \quad (2)$$

A smearing margin was applied to the compensators based on the clinical target volume (CTV) to account for setup and internal motion uncertainty.[7]

$$\text{Smear} = \sqrt{\left[(\text{setup error}+\text{internal motion})^2+(3\% \times \text{range})^2\right]} \quad (3)$$

The block margin was expanded from the isotropically expanded planning target volume (PTV), which is used for evaluation purposes only.

$$\text{Block margin} = \text{setup uncertainty} + \text{penumbar } (95\%-50\%) \quad (4)$$

We designed 4 smooth compensator plans and compared them with the original plunged-depth plan. The “smooth base (SB)” plan is a copy of the original plunged-depth plan with the same parameters, but the compensator milling design was changed to smooth. This plan was created to see if the smooth compensator would generate the same results as the plunged-depth plan without any modification. The SB plan consistently lacked coverage laterally to the CTV; therefore, we investigated alternative planning techniques to improve the CTV coverage. This plan is the base plan for which the other 3 smooth compensator plans are modified. The 3 additional smooth compensator plans were double smear (DS), PTV + 1 cm, and manual edits (ME). The DS plan had doubled the calculated smear value with all other parameters unchanged. The DS technique modified the compensator globally to see if the additional smear would improve lateral CTV coverage. The PTV + 1 cm plan added an additional 1 cm to the PTV, which was used for the compensator design only. The proximal and distal margins were still calculated from the CTV. The aperture margin was expanded from the CTV as well. The goal of this technique was to force additional compensator design laterally to the field border to help with lateral CTV coverage. 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. All 4 smooth compensator plans were generated for each patient in each site. The differences in the compensator design for 1 field can be seen in Fig. 1. The plans were designed to maintain the minimum amount of PTV coverage as the original plunged-depth plan so that they could be easily comparable.

### *Data collection and statistical analysis*

The Quality Reports [EMR] technology by Canis Lupus LLC with multicriteria (MCA) plan quality metrics was used for plan assessment and comparison. The site-specific algorithms were developed based on tumor dose and coverage and normal structures maximum and mean doses allowed. Conformality index, homogeneity index, and inhomogeneity index were added to each algorithm. The inhomogeneity index was calculated with the following formula: (max dose to PTV − min dose to PTV)/mean dose to PTV, and the homogeneity index was calculated by evaluating the (dose covering 1% PTV − dose covering 99% PTV)/prescription dose.

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 results for each individual criterion were scored based on a parameter range specific to that criterion. 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. The result for each plan criteria was converted to a performance value based on where the result fell within the range. A MCA metric algorithm for the lung is shown in Fig. 2. The dosimetric, plan, and performance results were analyzed for each plan and referenced to the plunged-depth plan. A paired t-test ($p < 0.05$) was used to evaluate the differences between the each smooth compensator plan and the plunged-depth plan.

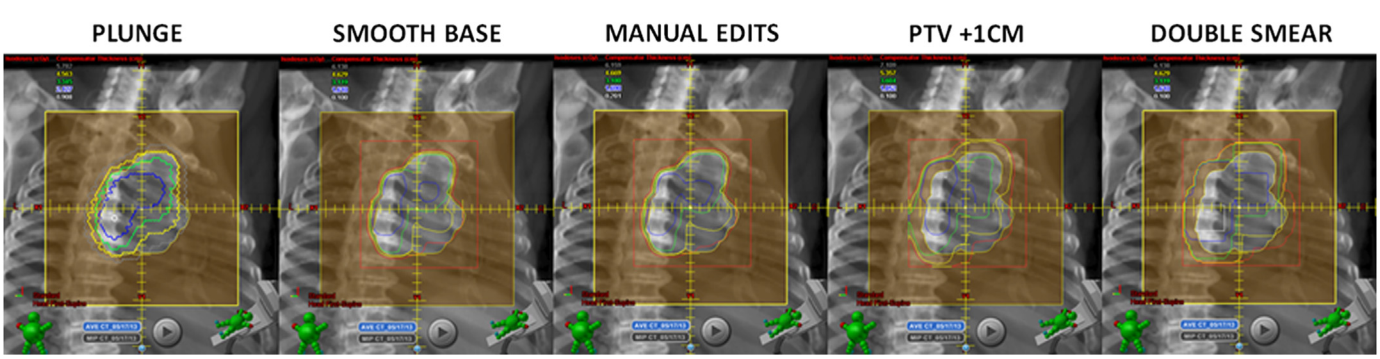


**Fig. 1.** Compensator designs for each smooth compensator technique for a lung patient. (Color version of figure is available online.)