Improving Head and Neck Cancer Treatments Using Dynamic Collimation in Spot Scanning Proton Therapy

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Abstract

Purpose: Interest in using collimation for spot scanning proton therapy has recently increased in an attempt to improve the lateral penumbra. To investigate the advantages of such an approach for complex targets, a plan comparison between uncollimated and collimated beam spots was performed for patients with head and neck cancer.

Patients and Methods: For 10 patients with head and neck cancer, previously treated with spot scanning proton therapy, uncollimated and collimated treatment plans were created using an in-house treatment-planning system capable of modeling asymmetric-beamlet dose distributions resulting from the use of a dynamic collimation system. Both uncollimated and collimated plans reproduced clinically delivered plans in terms of target coverage. A relative plan comparison was performed using both physical and radiobiological metrics on the organs at risk.

Results: The dynamic collimation system improved dose-distribution conformity while preserving target coverage. The median reduction of the mean dose to the esophagus, uninvolved larynx, and uninvolved parotids were –11.9% (minimum to maximum, –6.4% to –24.1%), –7.2% (–0.8% to –60.1%), and –5.2% (–0.2% to –21.5%), respectively, and depended on the organ location relative to the target and radiation beam angle. The collimation did not improve dose to some organs at risk surrounded by the target or located upstream of Bragg peaks because of the priority on the target coverage.

Conclusion: In spot scanning proton therapy, the dynamic collimation system generally affords better target conformity, which results in improvement in organ-at-risk sparing in the head and neck region while preserving target coverage. However, the benefits of collimation and the increased complexity should be considered for each patient. Patients with large bilateral targets or organs at risk surrounded by the target showed the least benefit.

Keywords: spot scanning proton therapy; collimation; head and neck

Introduction

Low-energy spot scanning proton therapy (SSPT) treatments suffer from poor conformity because of increased lateral spot size [1–3], which is further increased with patient scattering. Wang et al [1], van de Water et al [2], and Widesott et al [3] have found that, to improve plan quality over the state-of-the-art photon techniques for brain or head and neck cancers, the in-air spot size, defined as the sigma (σ air) of the Gaussian function used to...
represent fluence in the beam’s eye view of a proton pencil beam, must have a value of approximately 4 mm. Unfortunately, spots of this size at low energies do not seem achievable with current clinical equipment [4–6], even with the IBA-dedicated nozzle (IBA International, Louvain-La-Neuve, Belgium) which is known to have one of the smaller spot sizes commercially available [7]. However, collimation devices for SSPT, such as apertures or multileaf collimators, can potentially reduce the effective $\sigma$ of a proton pencil beam and improve overall plan quality [8, 9]. Hyer et al [10, 11] recently proposed a theoretical novel dynamic collimation system (DCS) with a small footprint that can provide collimation to SSPT at each beam spot.

An earlier study [12] investigating the clinical benefits of the DCS for brain treatments found that the DCS was able to greatly improve target conformity and normal tissue sparing, while maintaining target coverage, with an average mean dose reduction to normal brain tissue of 25.1%. Although head and neck cancers often have much larger target volumes and more-complex shapes than do the brain tumors studied previously, we believe that these patients may also benefit from the use of the DCS, largely because target volumes are often located near many organs at risk (OARs). With the ability to reduce the effective spot size and further improve dose conformity, using the DCS in SSPT is expected to increase or maintain tumor control probability while decreasing acute and late toxicities [13]. The purpose of this study was to evaluate the use of the DCS for head and neck tumors and retrospectively quantify the benefits of the DCS in 10 patients previously treated with SSPT.

**Materials and Methods**

**Patient Selection and Planning Method**

Treatment planning images and data for 10 patients with head and neck cancer (Table 1) treated previously at the University of Pennsylvania Proton Therapy Center (Philadelphia) were obtained through an institutional review board–approved
research protocol and data sharing agreement. The patients were originally planned using a commercial proton treatment planning system (Eclipse version 11, Varian Medical Systems, Palo Alto, California) and treated on an IBA ProteusPlus system equipped with a Universal Nozzle. The plan characteristics are summarized in Table 1. The beam characteristics of the Universal Nozzle are described by Lin et al [14]. The clinical plans used SSPT with a single-field optimization approach, except for 2 plans (P2 and P3) that utilized a boost planned with multifield optimization. The single-field optimization considers each beam individually, whereas the multifield optimization takes into account all beams simultaneously. The plans were optimized to pencil beam-scanning planning target volumes (PBSTV), which are defined as a 5-mm uniform expansion from the clinical target volume to account for setup and range uncertainties. Some plans had multiple PBSTVs with different dose prescriptions that were joined in a structure named the PBSTV composite for ease of display and analysis of the dose-volume histogram (DVH) curves. The PBSTV composite volumes for patients P1 to P10 were 500, 1004, 591, 822, 290, 436, 305, 200, 272, and 332 cm³, respectively. Other plan characteristics, such as individual PBSTV volumes, dose prescriptions, and beam incidences, are described in Table 1. The initial clinical plans were designed such that 95% of each PBSTV received the prescribed dose. The OAR dose constraints used for planning purposes were mean dose ($D_{\text{mean}}$) < 20 Gy for the esophagus, larynx, oral cavity, and contralateral parotid; $D_{\text{mean}}$ < 26 Gy for the ipsilateral parotid, $D_{\text{mean}}$ < 39 Gy for the contralateral submandibular gland; maximum dose ($D_{\text{max}}$) < 54 Gy for the brain stem, $D_{\text{max}}$ < 45 Gy for the cord, and $D_{\text{max}}$ < 50 Gy for the 5-mm expansion of the cord.

The clinically delivered SSPT plans were used as a reference to which uncollimated plans generated by our in-house treatment-planning system RDX were matched, mainly in terms of target coverage. RDX has been previously used for other studies involving proton-dose calculation [15, 16] and is capable of modeling asymmetric beamlets resulting from collimation [17]. The ability of RDX to calculate both collimated and uncollimated treatment plans eliminates any variance from different planning systems and allows the benefits of the DCS to be directly quantified. The beam angles of uncollimated and collimated plans in RDX were chosen so that the beam entered parallel to the long axis of the target structure, as shown in Figure 1. These beams are consistent with recommendations of Frank et al [18], who suggested an angle selection based on the premise of placing the Bragg peaks lateral to the spinal cord and minimizing the uncertainties produced by density heterogeneities along the beam path by avoiding beams going through the mouth and teeth. The initial PBSTV outlines of bilateral targets were split into left and right sides using the middle line to benefit from the spot collimation for OARs in the middle of the neck surrounded by the bulky target. A left posterior beam was used to calculate the left target beamlets, whereas a right posterior beam was used for the right target. Then, both beamlet batches were merged for the optimization calculation of beamlet weights.

A model of the IBA Universal Nozzle was used for the uncollimated plans in RDX. For the collimated plan, the effects of the DCS were added to the IBA Universal Nozzle. The modeling of the collimated beamlets for the clinical range of proton energy was validated and implemented in RDX by Gelover et al [17]. The spot spacing used for the plans was 3 mm, and energy layer separation was 5 mm. Both the spot spacing and energy layer separation were different from those used for the initial clinical plans. The rationale for using a reduced $x$ to $y$ spot spacing is that a smaller $\sigma$ size must be compensated for by reducing the distance between spots to obtain adequate coverage without hot spots [3]. The energy layer separation was set to be constant in RDX, whereas it was varying with energy based on the incident energy spread of the beam in Eclipse. Once the
uncollimated plans were generated, collimated plans were created in RDX using the same gantry angles, beam spots, and energy layers for comparison purposes, but future collimated plans outside the scope of this study might be planned using optimized beam angles. Although the DCS is theoretically able to collimate each beam spot, only spots around the target boundary were collimated in practice because the beam spots inside the target do not need collimation. As shown by Wang et al [19], the use of a collimation requires considering a target expansion for spot placement to ensure the target coverage: in this study, a 6-mm margin was chosen because that is the maximum displacement of the beamlet centroid by the DCS obtained through simulation by Gelover et al [17].

Evaluation Tools
The cumulative DVH curves of the target and OARs were used for initial evaluation. A focus on either the $D_{\text{mean}}$ or the $D_{\text{max}}$ dose ($D_{1\%}$) was made depending on the OAR, with $D_{1\%}$ corresponding to 1% of the organ volume on the cumulative DVH. The PBSTV coverage was assessed using $D_{95\%}$ of each individual PBSTV volume. The homogeneity index (HI) and conformity index (CI 50%) were calculated for further evaluation of the treatment plans. The HI is defined as the difference between the dose received by at least 95% of the PBSTV volume and the dose received by at least 5% of the PBSTV, normalized to the PBSTV $D_{\text{mean}}$: $(D_{95\%} - D_{5\%})/D_{\text{mean}}$. The CI 50% is the ratio between the patient volume receiving at least 50% of the prescribed dose and the PBSTV volume. The PBSTV coverage and HI were chosen to quantify the PBSTV dose distribution similarity between the uncollimated and collimated plans, whereas the CI 50% was chosen to quantify any improvement in

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dose distribution conformity. For OARs, $D_{\text{mean}}$ or $D_{1\%}$ are reported. In the analysis, an uninvolved structure means the part of the structure that was outside any planning target volume.

Normal tissue complication probability (NTCP) was calculated for the parotid glands, esophagus, oral cavity, and cord using the Lyman-Kutcher-Burman model [20]; the parameters for the computation were summarized by Luxton et al [20] and Jakobi et al [21].

The RayStation treatment planning system (version 3.99, RaySearch Laboratories, Stockholm, Sweden) was used to render dose distributions and compute the DVH for the both uncollimated and collimated plans.

Statistical significance was evaluated with a Student $t$ test to provide a 95% confidence interval (95% CI) and a $P$ value.

Results

Target Coverage

The equivalence of target coverage in the uncollimated and collimated plans was verified through the comparison of the PBSTV DVH, the 95% PBSTV coverage, and the HI. Although most patients have more than one target volume, for simplicity, only the comparison of the PBSTV composite DVH is shown in Figures 2 and 3. The PBSTV DVHs were nearly identical. Only small discrepancies were observed (maximum difference of 1.4%) for the PBSTV coverage and a close HI (maximum difference of 0.02) as reported in Tables 2 and 3 for all patients.

Dose-Conformity Improvement and Organ-at-Risk Dose Reduction

Dose distributions from the uncollimated and collimated plans and the difference for one patient (P5) are shown in Figure 4. The improvement in target conformity can be directly observed in the dose difference in Figure 4c. The values of CI 50% are reported in Tables 2 and 3 to demonstrate the improvement in conformity afforded by the DCS as well as the variability depending on the target volume and shape. The conformity improvement by the DCS was also observed through the significant reduction of the mean dose to the 10-mm ring surrounding the PBSTV, yielding an average decrease of 7.1% (95% CI, 4.4% to 9.8%; $P$ value < .001).

The collimated and uncollimated plans were also compared in the DVHs of selected OARs, as shown in Figures 2 and 3. The collimated plans showed reduced $D_{\text{mean}}$ or $D_{1\%}$ to OARs adjacent to the target compared with the uncollimated plan.
values for selected OARs are reported in Tables 2 and 3. For each patient, a graphical summary of the OAR having a $D_{\text{mean}}$ or $D_{1\%}$ difference $>\pm2\%$ (arbitrary value) between the uncollimated and collimated plan is shown in Figures 5 and 6.

### Toxicity Reduction through Radiobiological Modeling

The NTCP values for the toxicities affected by the DCS are presented in Table 4. The largest improvements of the parotid gland NTCP for the risk of xerostomia were observed in patients P1, P5, and P8. The largest improvements of the esophagus NTCP for acute toxicity were observed in patients P1 and P2. A noticeable improvement of the larynx NTCP for the risk of edema was only observed in patient P7. The largest improvements of the larynx NTCP for aspiration pneumonia were observed in patient P2, P4, and P7. Some NTCP values were increased after collimation, but none by $>0.7\%$.

### Discussion

The collimated plans maintained the target coverage of the uncollimated plans. Noticeable improvement of the OAR sparing was observed for most of the 10 head and neck plans. For parotid sparing, 5 of 10 patients benefitted from the addition of...
collimation. All patients benefitted from the addition of collimation in sparing of the uninvolved submandibular gland, because the $D_{\text{mean}}$ was systematically high (>34.7 Gy) in uncollimated plans and greatly reduced by the collimation (from $-5.0\%$ to $-35.5\%$). Four of 10 patients benefitted from the addition of collimation in sparing the uninvolved mandible, oral cavity, and the larynx and esophagus because the $D_{\text{mean}}$ values close to, or slightly beyond, the usual clinical constraints were reduced. Only 1 patient had a relatively minor benefit from collimation. In that case (P6), the dose to most OARs with the uncollimated plan were already sufficiently low relative to the clinical constraints used for the treatment planning; therefore, the small dosimetric improvement was not considered sufficient to advise the use of the DCS. Regarding the radiobiological metrics, Nguyen et al [22] showed that it is more reliable to focus on the relative difference of the NTCP values instead of the absolute difference because of NTCP model uncertainties. Based on this argument, the results provide evidence that the DCS affords a significant reduction in different complication probabilities; for instance, 6 of 9 plans had great relative reductions in xerostomia risk (NTCP to the parotids), suggesting potential clinical significance.

| Patient | Treatment | No. | Mean dose (cGy) | Max dose (cGy) | Mean dose (cGy) | Max dose (cGy) |
|---------|-----------|-----|----------------|---------------|----------------|---------------|
|         |           | Lt | Lt | Rt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt | Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | Rt |Lt | R
Results from the 10 patients also indicate that the therapeutic benefit of the DCS for the treatment of head and neck cancer by SSPT is dependent on beam orientation as well as properties of the target, such as its shape, volume, and location relative to the OAR. For instance, P9 had a great conformity improvement for each PBSTV, whereas P2 demonstrated little improvement in conformity. The major difference between P2 and P9 was the extent of the target; P2 had a bilateral PBSTV with a volume close to the full neck compared with the unilateral PBSTV of P9 with a volume nearly 4 times smaller than that for P2. The variability in OAR sparing depending on these parameters was also described by Jakobi et al [21] when comparing intensity-modulated photon therapy to intensity-modulated proton therapy to identify a subgroup of patients who would most benefit from proton therapy. In the present study, unilateral targets generally benefitted the most from collimation by normal tissue sparing; however, fewer OARs are likely to be spared with unilateral targets than with bilateral targets because of the lesser extent of the disease. These bilateral targets are also challenging because of target coverage robustness from the splitting of the target structure to benefit from the dynamic collimation for the OARs in the middle of the neck.

The benefit of DCS remains theoretical because this was an in silico study. In addition, this study evaluated only a subset of head and neck plans, which may not be representative of all head and neck tumors encountered in clinical practice or in other tumor locations. Many variables influence target conformity, such as the energy layer, spot spacing, spot size, and the use of range shifter. However, those values were chosen to be representative of clinical plans and were identical between the uncollimated and collimated plans, except for the spot size and spot spacing, because the collimation changes the spot geometry (sharper penumbra and asymmetry) requiring a slight spot-spacing reduction. A previous study based on brain tumor plans [12] can be used as a point of comparison to detail the behavior of a DCS-based plan, depending on the plan and target properties. For the head and neck plans, improvement in $D_{\text{mean}}$ to the 10-mm ring of normal tissue surrounding the target was slightly more than one-half of that obtained for the brain plans (−7.1% versus −13.7%). The main difference was that the brain tumors were smaller and more regularly shaped. The principal challenges with the head and neck plans included large target volumes with little ability to spare normal tissue, bulky tumors wrapped around the OAR with part of the beam crossing through the OAR to reach the target, and OARs partially intersecting the target or directly at the target boundary (Supplementary Data 1, 10.14338/IJPT-15-00036.1.S1). A minor challenge was related to a slight increase in the entrance dose by the DCS [17]. Given these challenges, the DCS did not yield uniform improvement in sparing for every OAR for each plan. Although general conclusions can be drawn from this study, the use of the DCS must still be considered for each individual plan by weighing the clinical benefit against the additional...
complexity. The DCS can be considered an optional collimation system offering plan improvement dependent on the target complexity and at a low-cost for treatment delivery time (theoretically, between 29 s and 84 s, depending on the target size and the number of beams, assuming a continuous motion of the trimmer blades at a velocity of 0.35 m/s).

Future developments with an adaptive method for spot placement using contour scanning and eliminating spots too far away from the target boundary are expected to further decrease the dose to normal tissue and to partially solve the limited improvement for OARs surrounded by the target in patients with head and neck cancer.

Conclusion

In SSPT, the DCS generally affords better target conformity, which results in an improvement in OAR sparing in the head and neck region while preserving target coverage. However, the benefits of collimation and increased complexity should be considered for each patient. Patients with large bilateral targets or OARs surrounded by the target showed the least benefit.

ADDITIONAL INFORMATION AND DECLARATIONS

Conflicts of interest: This research was supported by IBA (Louvain-la-Neuve, Belgium).
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**Table 4. Absolute normal tissue complication probability (NTCP; %) for both the uncollimated (Uncol) and collimated (Col) plans, and their absolute difference NTCP<sub>collimated</sub> − NTCP<sub>uncollimated</sub> (relative difference to the uncollimated plan between parentheses) for relevant organs at risk.**

| Patient No. | Treatment | Parotid (%) | Esophagus (%) | Larynx (edema) (%) | Larynx (aspiration) (%) |
|-------------|-----------|-------------|---------------|---------------------|------------------------|
|             |           | Left        | Right         |                     |                        |
| P1          | Uncol     | 92.7        | 0.23          | 10.4                | 25.3                   | 17.8                   |
|             | Col       | 81.9        | 0.20          | 8.6                 | 25.7                   | 17.5                   |
|             | Difference| −10.8 (−11.7)| −0.03 (−13.5)| −1.8 (−17.4)        | 0.4 (1.7)              | −0.3 (−1.9)            |
| P2          | Uncol     | 100         | 31.6          | 9.5                 | 87.8                   | 39.3                   |
|             | Col       | 100         | 28.5          | 7.5                 | 88.1                   | 37.1                   |
|             | Difference| 0.0 (0.0)   | −3.1 (−9.8)   | −2.0 (−20.9)        | 0.3 (0.3)              | −2.3 (−5.7)            |
| P3          | Uncol     | 0.76        | 2.9           | 10.6                | 0.18                   | 3.2                    |
|             | Col       | 0.74        | 2.0           | 9.5                 | 0.03                   | 2.6                    |
|             | Difference| −0.02 (−2.6)| −0.9 (−32.0)  | −1.1 (−10.3)        | −0.15 (−82.8)          | −0.6 (−21.3)           |
| P4          | Uncol     | 0.52        | 96.0          | 2.8                 | 9.8                    | 14.4                   |
|             | Col       | 0.08        | 87.6          | 1.9                 | 12.7                   | 12.7                   |
|             | Difference| −0.44 (−84.3)| −8.4 (−8.7)  | −0.9 (−30.7)        | 2.9 (29.2)             | −1.7 (−12.1)           |
| P5          | Uncol     | —           | 41.9          | 1.4                 | 81.6                   | 55.3                   |
|             | Col       | —           | 32.2          | 1.4                 | 81.8                   | 54.7                   |
|             | Difference| —           | −9.7 (−23.0)  | 0.0 (2.2)           | 0.2 (0.2)              | −0.6 (−1.0)            |
| P6          | Uncol     | 99.3        | —             | 4.6                 | 1.9                    | 4.5                    |
|             | Col       | 99.3        | —             | 3.6                 | 1.5                    | 3.7                    |
|             | Difference| 0.1 (0.1)   | —             | −0.9 (−20.5)        | −0.4 (−18.6)           | −0.8 (−17.2)           |
| P7          | Uncol     | —           | —             | —                   | 8.8                    | 5.7                    |
|             | Col       | —           | —             | —                   | 3.6                    | 3.4                    |
|             | Difference| —           | —             | —                   | −5.2 (−59.4)           | −2.4 (−41.2)           |
| P8          | Uncol     | 44.3        | 90.5          | 0.3                 | 74.2                   | 12.7                   |
|             | Col       | 42.0        | 79.2          | 0.3                 | 74.9                   | 12.7                   |
|             | Difference| −2.3 (−5.2)| −11.3 (−12.5) | 0.0 (−3.3)          | 0.7 (1.0)             | 0.1 (0.4)             |
| P9          | Uncol     | 100         | —             | 0.27                | 4.4                    | 5.2                    |
|             | Col       | 100         | —             | 0.27                | 3.7                    | 4.3                    |
|             | Difference| 0.0 (0.0)   | —             | 0.0 (0.0)           | −0.8 (−16.9)           | −0.9 (−17.8)           |
| P10         | Uncol     | 100         | —             | 0.28                | 5.2                    | 4.5                    |
|             | Col       | 100         | —             | 0.27                | 4.5                    | 3.7                    |
|             | Difference| 0.0 (0.0)   | —             | −0.01 (−3.6)        | −0.7 (−12.9)           | −0.9 (−18.8)           |
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