Robust treatment planning using virtual bolus for extremity sarcoma patients receiving VMAT

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I. Abstract

Soft tissue sarcomas (STS) treated with volumetric modulated arc therapy (VMAT) are susceptible to tumor volume changes resulting in increased surface dose and loss of target coverage; however, few solutions exist to correct these dosimetric issues aside from adaptive replanning. Incorporating skin flash for VMAT optimization using virtual bolus (VB) can produce robust treatment plans that are more resistant to volume changes and setup uncertainties than conventional planning methods. The purpose of this study was to compare extremity sarcoma VMAT plans with and without VB and determine if planning target volume (PTV) coverage can be maintained while minimally increasing plan maximum dose on subsequent verification scans. Thirteen patients with superficial soft tissue sarcomas of the extremities were selected. Treatment plans were created using VMAT with and without VB for each patient. An artificial tissue expansion was applied to the planning CT scans and plans were re-calculated to assess dosimetric changes. The primary metrics evaluated included differences in plan maximum dose, skin maximum dose, PTV volume receiving 100% of the prescription dose ($V_{100\%}$), and PTV volume receiving 95% of the prescription dose ($V_{95\%}$). The $P$-values for change in plan maximum dose, change in skin maximum dose, and change in $V_{100\%}$ to the PTV were $\leq 0.001$, indicating statistically significant differences between plans with and without VB. Confidence intervals for plan maximum dose and PTV coverage also indicated that plans with VB maintained acceptable plan maximum doses and $V_{95\%}$ to the PTV after volume changes were applied.

Keywords: VMAT, sarcoma, robust treatment planning, virtual bolus, skin flash, radiation therapy
II. Introduction


C. PIII: Indications for soft tissue sarcoma replanning (Reference: Boyd et al,9 Abu-Hijlih et al,2)

D. PIV: Principles of virtual bolus for VMAT planning, as established for breast radiation therapy (Reference: Rossi et al,6 Tyran et al,10 Lizondo et al,11)

E. PV: Summarize key points of introduction

1. Problem Statement: The problem is that VMAT plans for extremity sarcoma cases often require replanning due to increases in maximum plan dose and decreases in PTV coverage that result from changes in tumor volume during treatment.

2. Purpose: The purpose of this study is to compare extremity sarcoma VMAT plans with and without virtual bolus and determine if PTV coverage can be maintained while minimally increasing plan maximum dose on subsequent verification scans.

3. Hypothesis Statements: The research hypothesis statements used to guide the study were (H1_A) the difference in plan maximum dose between initial and the verification plans will be less with virtual bolus than without virtual bolus; (H2_A) the increase in plan maximum dose in verification plans with virtual bolus will not exceed 5% from the initial plan; (H3_A) the difference in skin maximum dose between initial and the verification plans will be less with virtual bolus than without virtual bolus; (H4_A) verification plans with virtual bolus will better maintain coverage of the 100% isodose line (V_{100%}) for the PTV compared to plans without virtual bolus; and (H5_A) verification plans with virtual bolus will maintain coverage of the 95% isodose line (V_{95%}) ≥ 95% coverage for the PTV.

III. Materials and Methods

a. Patient Selection and Setup
i. PI: Patient Selection
   1. 13 patients with extremity sarcomas
   2. Inclusion Criteria
      a. Patients treated in the last 3 years
      b. Over 18 years old
      c. Superficial tumors / target volumes close to skin
   3. Exclusion Criteria
      a. Non-superficial tumors
      b. Target volumes greater than 40cm in length

ii. PII: Patient Setup
   1. CT simulation
      a. GE Discovery CT scanner
   2. Patient treatment extremity immobilized in vac-loc bag
   3. Treatment site abducted from unaffected limb

b. OAR and Planning Structures
   i. PI: Contouring
      1. Target volumes, OAR, and planning objectives partially adopted from RTOG 063012
      2. Planning Structures
         a. PTV3mmEval (Figure 1)
            i. Crop PTV 0.3cm from external
         b. PTV7mm (add 7mm to PTV) (Figure 1)
            i. Crop structure within 0.5cm skin
         c. PTVFlash (add 15mm margin to PTV7mm) (Figure 1)
            i. Crop out of PTV3mmEval by 0.1cm
         d. External15mm (Figure 2)
            i. External + 1.5cm expansion
         e. ResOverride_Tis (Figure 2)
            i. Crop External15mm out of original external
               ii. HU = -101 (adipose tissue)
         f. SkinNew_5mm (Figure 2)
i. 0.5 cm rind from External15mm

3. Bolus (2cm) (Figure 1)
   a. HU value: -400 (Lizondo et al\textsuperscript{11})

c. Treatment Planning
   i. PI: Plan Parameters/Technique
      1. Planned using Eclipse with Acuros XB version 16.1.0
      2. Varian Truebeam Linear Accelerator
      3. All plans VMAT, 2-4 partial arcs depending on length of PTV, varying gantry angles, collimator angles, and field size
      4. Normalization: 100% of the prescription dose covering 95% of the target volume

d. Plan Comparison Tables
   i. PI: Compare plan maximum dose between plans with and without VB on verification plans and location
   ii. Compare V100% PTV coverage between plans with and without VB on verification plans

e. Statistics (UW-La Crosse Statistics Center)
   i. PI: T-Test Pi: T-Test
      1. Plan maximum dose between plans with and without VB on verification plans (H1\textsubscript{A})
      2. Skin maximum dose between plans with and without VB on verification plans (H3\textsubscript{A})
      3. V100% PTV coverage between plans with and without VB on verification plans (H4\textsubscript{A})
      4. Significance level: P <0.05 is statistically significant
   ii. Descriptive summary of mean
      1. Increase in plan maximum dose for plans with VB on verification plans (H2\textsubscript{A})
      2. V95% PTV coverage for plans with VB on verification plans (H5\textsubscript{A})

IV. Results
   a. PI: Plan Maximum Dose
i. Evaluate plan maximum dose value between plans with and without VB on verification plans (H1A) (Table 1)
   1. P value = <0.001
   2. Reject null hypothesis
   3. The mean change in plan maximum dose with VB is statistically less than without VB.

ii. Evaluate plan maximum dose between initial and verification plans with VB (H2A) (Table 2)
   1. Reject null hypothesis
   2. The increase in plan maximum dose in verification plans with VB does not exceed 5% from the initial plan.

b. PII: Evaluate skin maximum dose between plans with and without VB on verification plans (H3A) (Table 1)
   i. P value = <0.001
   ii. Reject null hypothesis
   iii. The mean decrease in skin maximum dose with VB is statistically higher than without VB

c. PIII: PTV Coverage (Table 1)
   i. Evaluate $V_{100\%}$ PTV coverage between plans with and without VB on verification plans (H4A)
      1. P value = <0.001
      2. Reject null hypothesis
      3. The mean $V_{100\%}$ PTV coverage with VB is statistically higher than without VB.
   ii. Evaluate $V_{95\%}$ PTV coverage between plans with VB on verification plans (H5A) (Table 2)
      1. Reject null hypothesis
      2. The mean verification plan with VB maintains $V_{95\%}$ PTV coverage.

V. Discussion
   a. PI: Volume Change and Plan Robustness
i. Discuss significance of results
   1. Plan maximum dose, skin maximum dose, PTV coverage
   2. Explanation of the benefit of virtual bolus in terms of hypotheses
   3. Clinical significance with volume changes
b. PII: Wound Healing and Replanning
   i. Wound Healing Complications
      1. Tumor volume changes and skin maximum dose
      2. Hot spots near skin contour (Figure 3)
   ii. Replanning
      1. Reactive instead of proactive
      2. Time and resources of multiple departments
      3. Old treatment plan has already been delivered for multiple fractions
c. PIII: Virtual Bolus Robust Planning
   i. Skin crop effect
      1. Skin crop effect is greater with 3mm vs 5mm (5mm: Wang et al\textsuperscript{12}, ARST 1321; 3-5mm: ASTRO\textsuperscript{4})
      2. Hot spot effect with volume change more pronounced with 3 mm PTV crop from skin vs. 5 mm
      3. Recommend using 5mm crop to reduce hot spots in the skin
   ii. Virtual bolus
      1. Study design addresses ‘worst case scenario’, not volume changes observed in clinic
         a. Bolus thickness
         b. PTV crop
VI. Conclusion
   a. PI: Study and hypothesis summary
      i. **Problem:** The problem is that VMAT plans for extremity sarcoma cases often require replanning due to increases in maximum plan dose and decreases in PTV coverage that result from changes in tumor volume during treatment
ii. **Purpose:** The purpose of this study is to compare extremity sarcoma VMAT plans with and without virtual bolus and determine if PTV coverage can be maintained while minimally increasing plan maximum dose on subsequent verification scans.

b. PII: Study limitations and future studies

i. Limitations

1. Small sample size (n=13)
2. Artificially expanded limb to create ‘worst case scenario’, does not assess effects on actual volume changes observed in patients

ii. Future studies

1. Optimal HU value, bolus thickness, and PTV expansion
2. Clinical outcomes and dosimetric studies over course of treatment
3. Actual change in rate of replanning for extremity sarcomas

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References


Figure 1. Planning Structures used for initial bolus plans.

Figure 2. Structures created for verification plans to simulate 1.5 cm tissue expansion.
Figure 3. Axial and coronal views of verification plan without VB (a) and with VB (b).
### Table 1. Mean values, \(P\)-values, and the 95\% confidence interval of the difference for hypotheses H1\(_A\), H3\(_A\), and H4\(_A\).

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Mean</th>
<th>(t)-test</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference in Plan Maximum Dose between Initial and Verification Plans (H1(_A))</td>
<td>0.146</td>
<td>-0.00469</td>
<td>(&lt;0.001^*) 0.0959 0.206</td>
</tr>
<tr>
<td>Difference in Skin Maximum Dose between Initial and Verification Plans (H3(_A))</td>
<td>-0.00723</td>
<td>-0.132</td>
<td>(&lt;0.001^*) 0.0554 0.193</td>
</tr>
<tr>
<td>(V)(_{100%}) Coverage of Verification Plans (H4(_A))</td>
<td>0.725</td>
<td>0.931</td>
<td>(&lt;0.001^*) -0.310 -0.102</td>
</tr>
</tbody>
</table>

\(^*\) = \(P\)-value is statistically significant  
NB = Non-virtual bolus plan; VB = Virtual bolus plan; \(V\)\(_{100\%}\) = Treatment volume receiving 100\% of the dose

### Table 2. Mean values and the 95\% confidence interval of the mean for hypotheses H2\(_A\) and H5\(_A\).

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Mean</th>
<th>95% Confidence Interval of the Mean</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in VB plan maximum dose in verification plans from initial plan (H2(_A))</td>
<td>-0.00469</td>
<td>-0.0102</td>
<td>0.00079</td>
</tr>
<tr>
<td>(V)(_{95%}) Coverage of Verification Plans with VB (H5(_A))</td>
<td>0.990</td>
<td>0.987</td>
<td>0.994</td>
</tr>
</tbody>
</table>

VB = Virtual bolus; \(V\)\(_{95\%}\) = Treatment volume receiving 95\% of the dose