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# An investigation of the impact of variations of DVH calculation algorithms on DVH dependant radiation therapy plan evaluation metrics

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Abstract. Plan review systems often allow dose volume histogram (DVH) recalculation as part of a quality assurance process for trials. A review of the algorithms provided by a number of systems indicated that they are often very similar. One notable point of variation between implementations is in the location and frequency of dose sampling. This study explored the impact such variations can have on DVH based plan evaluation metrics (Normal Tissue Complication Probability (NTCP), min, mean and max dose), for a plan with small structures placed over areas of high dose gradient. Dose grids considered were exported from the original planning system at a range of resolutions. We found that for the CT based resolutions used in all but one plan review systems (CT and CT with guaranteed minimum number of sampling voxels in the x and y direction) results were very similar and changed in a similar manner with changes in the dose grid resolution despite the extreme conditions. Differences became noticeable however when resolution was increased in the axial (z) direction. Evaluation metrics also varied differently with changing dose grid for CT based resolutions compared to dose grid based resolutions. This suggests that if DVHs are being compared between systems that use a different basis for selecting sampling resolution it may become important to confirm that a similar resolution was used during calculation.

#### **1. Introduction**

Plan review and quality assurance (QA) systems are sometimes used during radiation therapy clinical trials to ensure the quality and consistency of data. This often includes recalculation of dose volume histograms (DVHs). Several studies demonstrated that variation in DVH calculation methods can lead to significant differences in resulting DVHs, which in turn can add unnecessary noise to DVH based plan evaluation [1, 2]. Plan review systems provide convenient access to DVHs, but not necessarily to original plans, with derived information used in presentation of trial outcomes analyses. Compatibility between DVH calculation algorithms is therefore desirable. Variations in DVH calculation algorithms were explored together with the impact of these variations on DVH based plan evaluation metrics.

1.1. Comparison of plan review DVH calculation algorithms

DVH calculation algorithms employed by several plan review/quality assurance systems (see table 1) were reviewed. We found that the algorithms were very similar and in general conformed to the assumptions outlined by the Image Guided Therapy QA Centre (ITC) [2], with VODCA allowing some greater flexibility in user-control that can mean the calculations do not conform to ITC

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assumptions. These assumptions are described in figure 1. In addition all the systems reviewed were consistent in their selection of 3D linear interpolation. One point on which the ITC assumptions are vague and on which the plan review systems differed is the selection of voxel sampling size. Table 1 presents the range of voxel sampling sizes used by different implementations of the algorithm. Variation in sampling resolution for the DVH calculation described by the ITC has an impact on both volume errors at the borders of the structures and on the points that dose is interpolated to. Previous research has suggested that high dose gradients and small structure sizes increase the sensitivity of DVHs to variations in DVH calculation assumptions [2-4].

ITC DVH Computation

Assumptions:

- 1. The patient anatomy and target structures are represented by axial, planar, closed loops at the center position of each CT scan.
- 2. The dose is represented as a 3D dose-grid covering the irradiated volume and sampled at a spatial rate sufficient to represent the continuous dose distribution.
- 3. Structures are defined as a set of stacked right prisms, whose shapes are defined by structure loops. Each prism is assumed to extend axially from one-half the distance to the next inferior slice location to one-half the distance to the next superior slice location. (The width of prisms at the superior-most and inferior-most slices is assumed to be twice the half-distance to the next neighboring slice location.)
- 4. The patient volume is broken into cubes of the "spatial sampling size".
- 5. The dose value at the center of each cube is interpolated in three dimensions from the dose-grid.
- 6. The DVH bin corresponding to the dose value of each contained cube is incremented by the cube volume. For I = 0,1,...,n-1, the i<sup>th</sup> bin of the histogram represents the structure volume receiving dose D, such that  $i\Delta \leq D < (i+1)\Delta$ , where  $\Delta$  is the bin width in Gy. (DVHs are displayed as cumulative functions where the i<sup>th</sup> bin represents the structure volume receiving dose  $\geq i\Delta$ )

# Figure 1. ITC assumptions [1] [5]

Tuble 1. Comparison of D vir agonumis for plan review systems. [0 0]			
Software	Structure capping at axial ends	Sampling voxel resolution	Interpolation
Swan <sup>1</sup>	As defined by ITC assumption 3	CT resolution, user selection	Linear 3D
CERR <sup>2</sup>	As defined by ITC assumption 3	CT resolution	Linear 3D
Slicer RT <sup>3</sup>	As defined by ITC assumption 3	2 * dose grid resolution, user	Linear 3D
		selection	
VODCA <sup>4</sup>	User chooses whether or not to extend half a slice beyond end slices in z direction	CT resolution as default but guarantees a minimum of 128*128 voxels in x and y direction of the bounding box of each slice.	Linear 3D

# Table 1. Comparison of DVH algorithms for plan review systems. [6-8]

#### 2. Method: examining the impact of sampling resolution

2.1. Algorithmic variations: separating volume and dose differences

<sup>&</sup>lt;sup>1</sup> Developed by the authors [5].

<sup>&</sup>lt;sup>2</sup> See [6-7]

<sup>&</sup>lt;sup>3</sup> Information from Andras Lasso (personal communication).

<sup>&</sup>lt;sup>4</sup> See [8], Details of assumptions received from Stefano Gianolini (personal communication).

We created a variation on the ITC algorithm that removes the volume error component by adding only the intersecting volume of sampling voxels and structure loops (Exact Voxel Interpolation or EVI). This allowed us to isolate the impact of changes in dose sampling from changes in volume estimation. It also allowed us to include in our comparisons the base case where sampling voxels are lined up with dose grid voxels so that no interpolation occurs but exact dose values are used (Exact Dose or ED). Figure 2 depicts these variations on the original algorithm. Chung et al [4] noted that dose could be varied by several percentage points just by shifting the origin of the dose grid calculated during treatment planning.



Figure 2. DVH calculation algorithmic variations on sampling and volume calculation strategies.

# 2.2. Dataset

We selected a stereotactic brain plan created with XiO (Elekta Pty Ltd) with the dose grid exported at resolutions (voxel sizes) from 1mm to 5mm in 1mm increments and at 2.5mm. The plan was selected for having steep dose-gradients (as high as 12Gy on the 0.25cm dose grid) and small structure volumes (ranging from 0.57cc to 26.6cc). Structures were shifted to lie over an area of high dose gradient. The CT slice width was 0.3cm.

# 2.3. Experimental variations

We compared the EVI variation at a range of resolutions including those used by different plan review systems listed in table 1 as well as the ED base case. We also included some higher resolutions for EVI including 2, 4 and 8 times the CT resolutions and a condition that extended VODCA's variable resolution algorithms to the axial (z) dimension. DVHs were calculated for 5 structures on all 5 dose grids.

# 2.4. DVH comparison/evaluation

We compared DVHs based on differences in normal tissue complication probability<sup>5</sup> (NTCP), and minimum, mean and maximum dose. We examined the differences between DVHs calculated at different resolutions and how these differences varied with change in dose grid resolution. We also examined how much DVH based metrics at a given sampling resolution changed over different dose grid export resolutions.

# 3. Results

Figure 3 shows the results of comparing DVH based plan evaluation metrics for each condition across different dose grid resolutions. We found that in general there was a strong impact of dose grid resolution on DVH based NTCP, max dose and to a lesser extent min dose. However differences do not start to get large until dose grid resolutions lower than 0.3cms are used.

<sup>&</sup>lt;sup>5</sup> The initial NTCP parameters were taken from Luxton et al [9] with TD50 then adjusted to ensure that NTCP values did not go to zero or one for this dataset.

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The way that DVH based metrics changed was very similar for EVI using CT based sampling resolutions compared to EVI at twice the dose grid resolution. Interestingly the ED algorithm, which is based on the dose grid resolution, results in differences to mean dose that follow those of EVI at the CT based resolution far more closely than the other dose grid based sampling resolution, EVI at twice the dose grid resolution. It seems that, especially in the case of max dose, interpolation smoothes out variations caused by a change in dose grid but that for NTCP aligning the sampling grid with the dose grid (ED) reduced variation with decreasing dose grid resolution.



**Figure 3.** Mean differences between DVH based plan evaluation metrics ( (a) NTCP, (b) mean dose, (c) min dose, (d) max dose) from values calculated on finest dose grid (0.1cm) with those calculated at lower dose grid resolution. The value for each algorithmic condition at dose grid resolutions greater than 0.1cm is subtracted from the value for that algorithm on a dose grid of resolution 0.1cm. Min, max and mean dose changes are presented as a percentage of the prescribed dose (60Gy).



**Figure 4.** Mean differences in NTCP values between different resolution/algorithm conditions at each dose grid resolution. (a) Differences between NTCP values calculated via EVI at several different CT based resolutions. Increased resolution in z impacted the NTCP far more than increased resolution in x and y. (b) Differences between EVI at CT based resolutions and ED. Increased EVI resolution increases similarity between ED and EVI.

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The CT based conditions display similar variations with changing dose grid resolution though there are significant differences in absolute values. Figure 4(a) displays comparisons between NTCP values generated by different algorithmic conditions. It is interesting to note that changes to the resolution in the z direction for EVI had a much greater impact than changes to the resolution in x and y. This could be partly explained by the higher mean dose gradients that existed for these structures in the z (5.37Gy) direction than for either x (1.87Gy) or y (3.71Gy). An examination of the variation for individual structures in comparison to each other suggested a relationship between mean dose gradient for the structure and the magnitude of variation in DVH based plan evaluation metrics between algorithms.

Figure 4(b) depicts differences between NTCP values produced by ED and EVI at different resolutions. Increasing the resolution of CT based EVI increased the similarity of EVI to ED for NTCP significantly.

#### 4. Discussion

In this study, the conditions under which variations were examined were fairly extreme. In cases where dose gradients were less extreme we found minimal variation in DVH based metrics. Most of the plan review systems used or permitted users to select CT based resolutions in any case, which suggests DVH comparability between systems.

The results suggest that in the presence of steep dose gradients, comparable sampling resolutions and dose grid resolutions would facilitate agreement between independent DVH calculation algorithms. They also suggest that under these conditions resolutions finer than the CT resolution or twice the dose grid resolution might be required to achieve high levels of confidence in DVH accuracy (this ignores any inaccuracies that may already exist in the plan data imported into the plan review system including dose calculation inaccuracies).

We attribute the increase in similarity between EVI and ED with increasing resolution of EVI to the fact that for dose voxels entirely inside the structure linear interpolation provides an approximation of the exact dose values. Increasing the resolution should improve this approximation. This would not be the case for voxels on structure borders where, given the dose is assumed to be continuous, interpolation should be more accurate.

Struabe et al [2] noted variations in assumptions with regard to how structures behave between slices in the z direction can have a significant impact on DVHs. In this case we certainly found that sampling resolution in the z direction had a noticeable impact on DVH based plan evaluation metrics. If DVHs need to be calculated on very small structures with high dose gradients it may be worth considering other methods of modelling change in the z direction such as interpolation of structure contours [10].

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