DVH Analysis: Consequences for Quality Assurance of Multi-Institutional Clinical Trials

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Abstract

Purpose: The submission of digital treatment planning data is essential for quality assurance (QA) of multi-institutional clinical trials involving advanced technology delivery techniques. Digitally submitted Dose Volume Histograms (DVHs), however, lack consistency, due to algorithmic differences among Treatment Planning Systems (TPSs). To maintain consistency among cases in multi-institutional clinical trials, the Image Guided Therapy QA Center (ITC) re-calculates DVHs from submitted 3-D dose distributions and structure contours. In some recent trials involving high dose gradients, sizeable discrepancies have been observed between DVHs re-calculated by the ITC and DVHs submitted by participating institutions, making QA review of these data more difficult.

Method and Materials: Digitally submitted DVH data were collected from various commercial TPSs for protocols requiring digital data submission. Submitted structure volumes and DVHs were compared to those calculated by the ITC. Comparisons were performed for anatomic structures ranging in size from < 1cc (optic chiasm) to > 450 cc (Lung PTV).

Results: Agreement between submitted and re-calculated DVHs varied with the spatial sampling algorithms used by TPSs and improved as the volume of structures increased. Discrepancies in excess of 15% were observed for structures with volumes < 50 cc.

Conclusion: Discrepancies in DVHs calculated by various commercial TPSs have long necessitated re-calculation of DVHs by the ITC for consistent correlation of dosimetry with outcomes. With increasing dose gradients, however, small changes in computed volumes can result in significant differences between dose coverage statistics reported by the treating institution and those computed for QA review. As a result, apparently protocol-compliant plans may be judged to violate QA criteria when submitted data are reviewed. Our analysis of DVH discrepancies among various TPSs can help to set QA criteria for present and future protocols, especially those in which high dose gradients are required.

Introduction

The submission of digital treatment planning data is essential for quality assurance (QA) of multi-institutional clinical trials involving advanced technology delivery techniques. Digitally submitted Dose Volume Histograms (DVHs), however, lack consistency due to algorithmic differences among Treatment Planning Systems (TPSs). To maintain consistency among cases in multi-institutional clinical trials, the ITC re-calculates DVHs from submitted 3-D dose distributions and structure contours. In some recent trials involving high dose gradients, sizeable discrepancies have been observed between DVHs re-calculated by the ITC and DVHs submitted by participating institutions, making QA review of these data more difficult.

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". Cubes whose centers are inside the prism are counted as belonging to the structure.
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 ith bin of the histogram represents the structure volume receiving dose D, such that $i\Delta \le D < (i+1)\Delta$, where Δ is the bin width in Gy. (DVHs are displayed as cumulative functions where the ith bin represents the structure volume receiving dose $\ge i\Delta$.)

Differing assumptions made in computing DVHs from planar contours and three-dimensional dose grids can result in differences in computed DVHs. Of particular importance are assumptions regarding

a. the manner in which the cross-section of structures varies with axial distance; and
b. the manner in which the dose to a voxel is interpolated from the dose grid (particularly in the axial dimension).

Among the commercial TPS with which we are familiar, there is some variability in the assumptions used to calculate DVHs. For example, some TPSs assume structures are composed of right prisms, while others use smoothing in the axial dimension. In addition, some TPSs interpolate doses to the axial position of each voxel, while others use doses interpolated to the center of an *image* plane for all voxels within that plane.

Methods And Materials

Digitally submitted DVH data were collected from various commercial TPSs for protocols requiring digital data submission. Submitted structure volumes and DVHs were compared to those calculated by the ITC. Comparisons were performed for anatomic structures ranging in size from < 1cc (optic chiasm) to > 450 cc (Lung PTV) (Fig 1). Volumes were compared for five different 3D TPSs. DVHs were compared for TPSs representing six different vendors: three IMRT systems (Fig 2), two 3D systems (Fig 2), two HDR brachytherapy systems (Fig 3), and two Stereotactic Body Radiation Therapy (SBRT) systems (Fig 4 and 5).
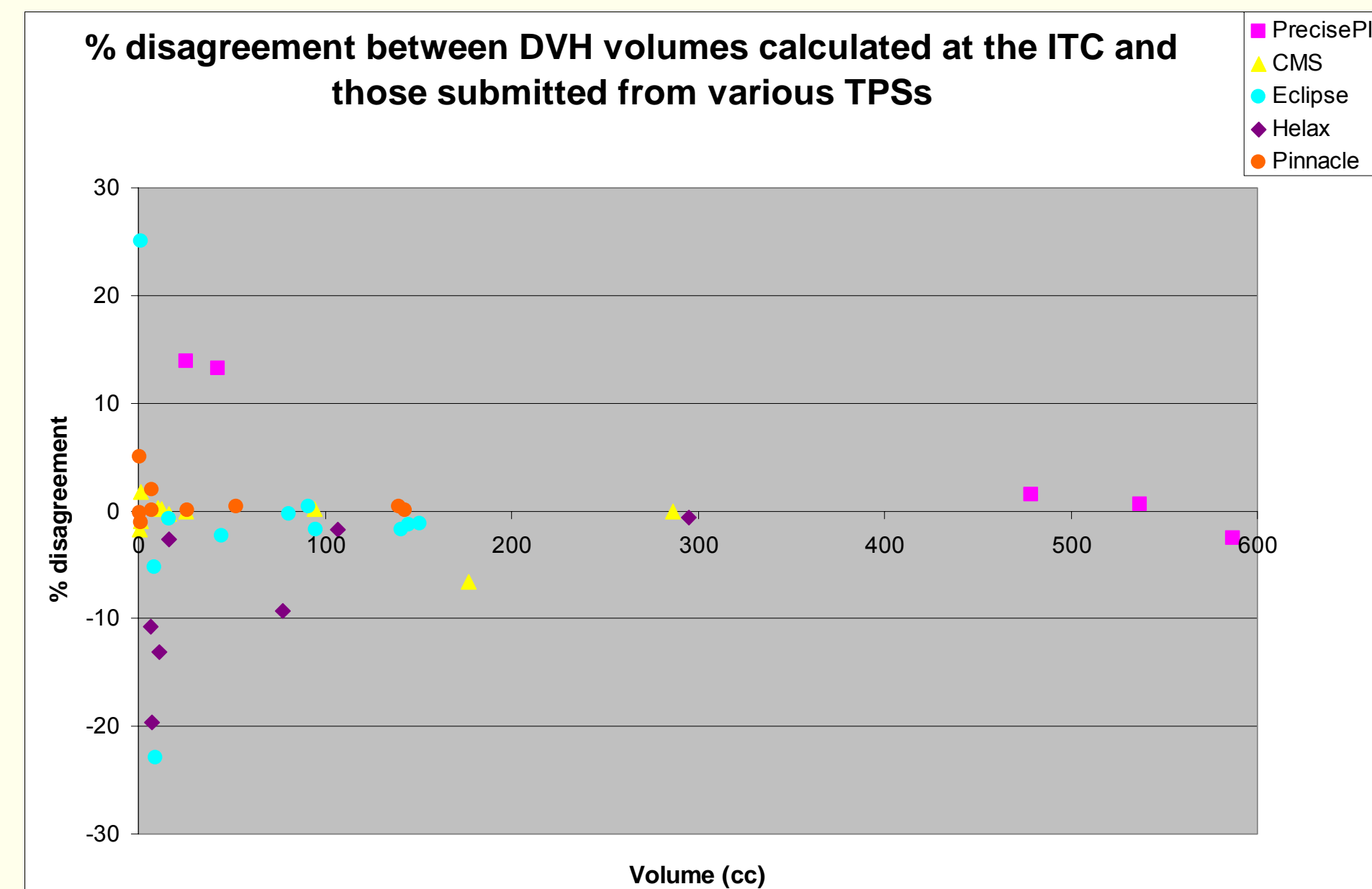

Fig. 1. A plot illustrating discrepancies between structure volumes computed by the ITC and those submitted digitally from five commercial 3DCRT Treatment Planning Systems: Elekta PrecisePlan, CMS FOCUS/XiO, Varian Eclipse, Nucletron Helax TMS, and Philips Pinnacle[3].
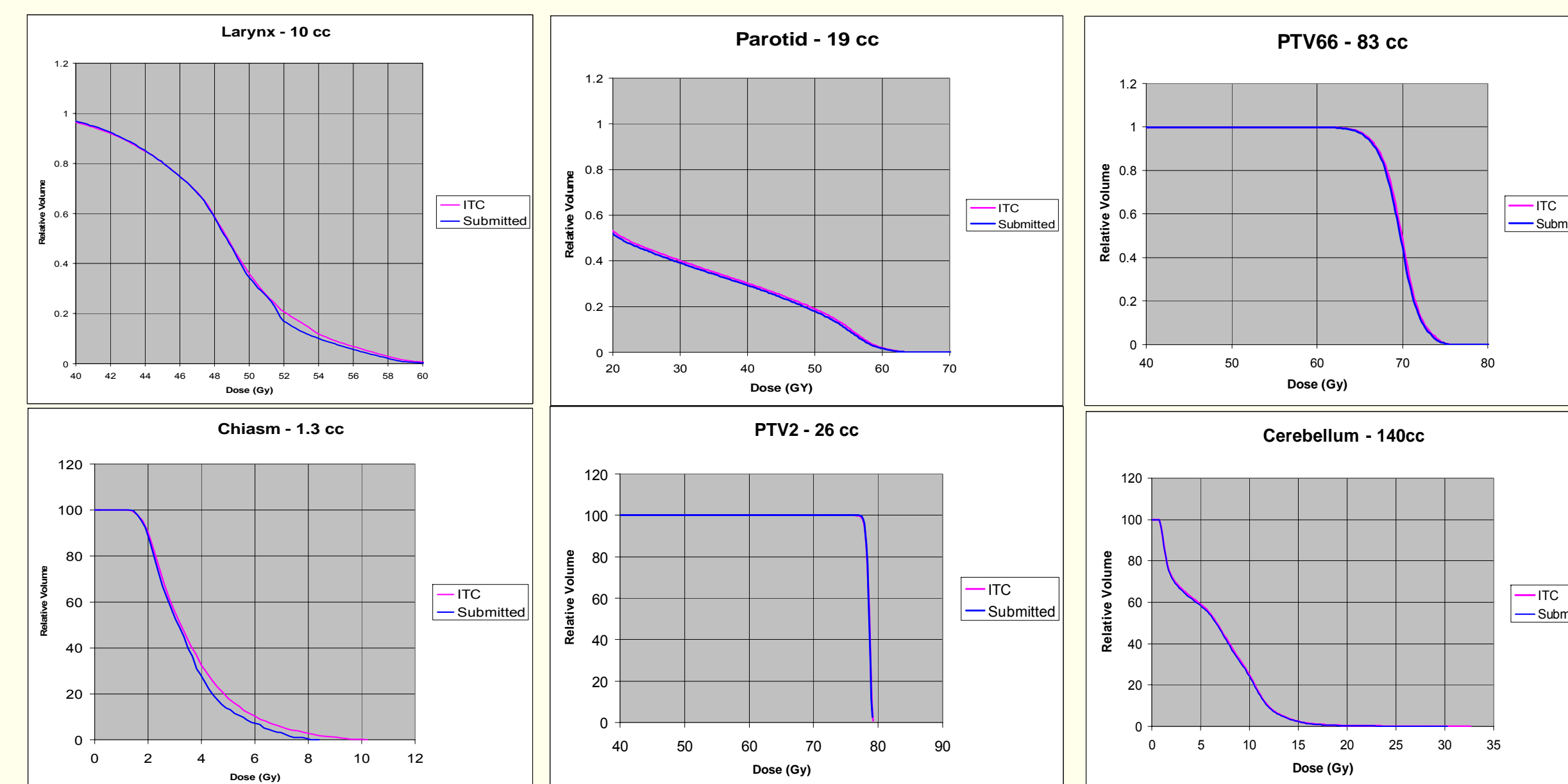

Fig. 2. Plots illustrating discrepancies between submitted DVHs and those calculated by the ITC for IMRT and 3DCRT for a single treatment planning system (Pinnacle). The differences are much more pronounced for the small volumes. For larger volumes, the differences are negligible.
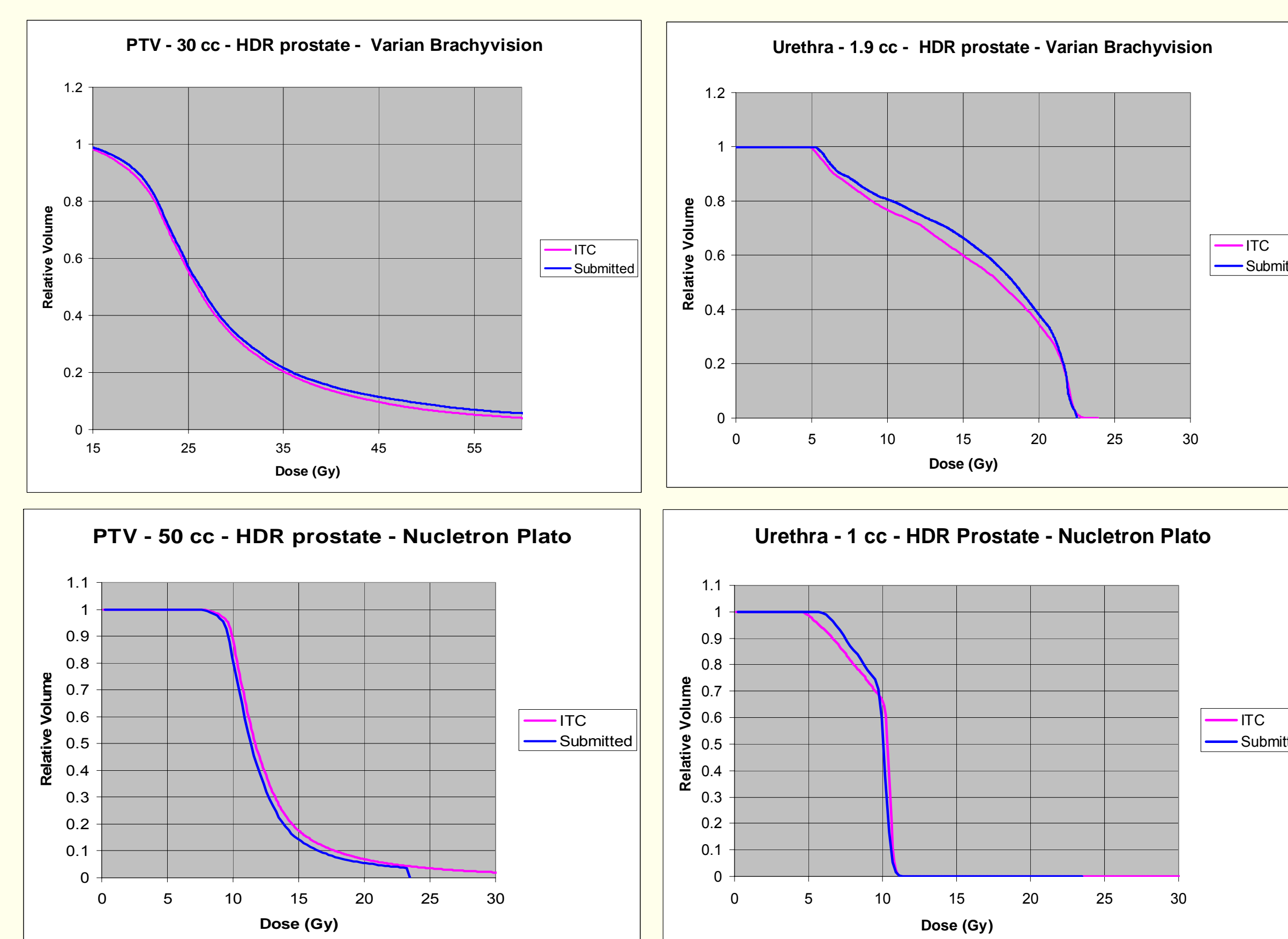

Fig. 3. Four Plots illustrating discrepancies between submitted DVHs and those calculated by the ITC for HDR brachytherapy plans for two different treatment planning vendors. The differences are much more pronounced for the small volumes, but even the larger volumes show discrepancies due to the high dose gradient for HDR brachytherapy.
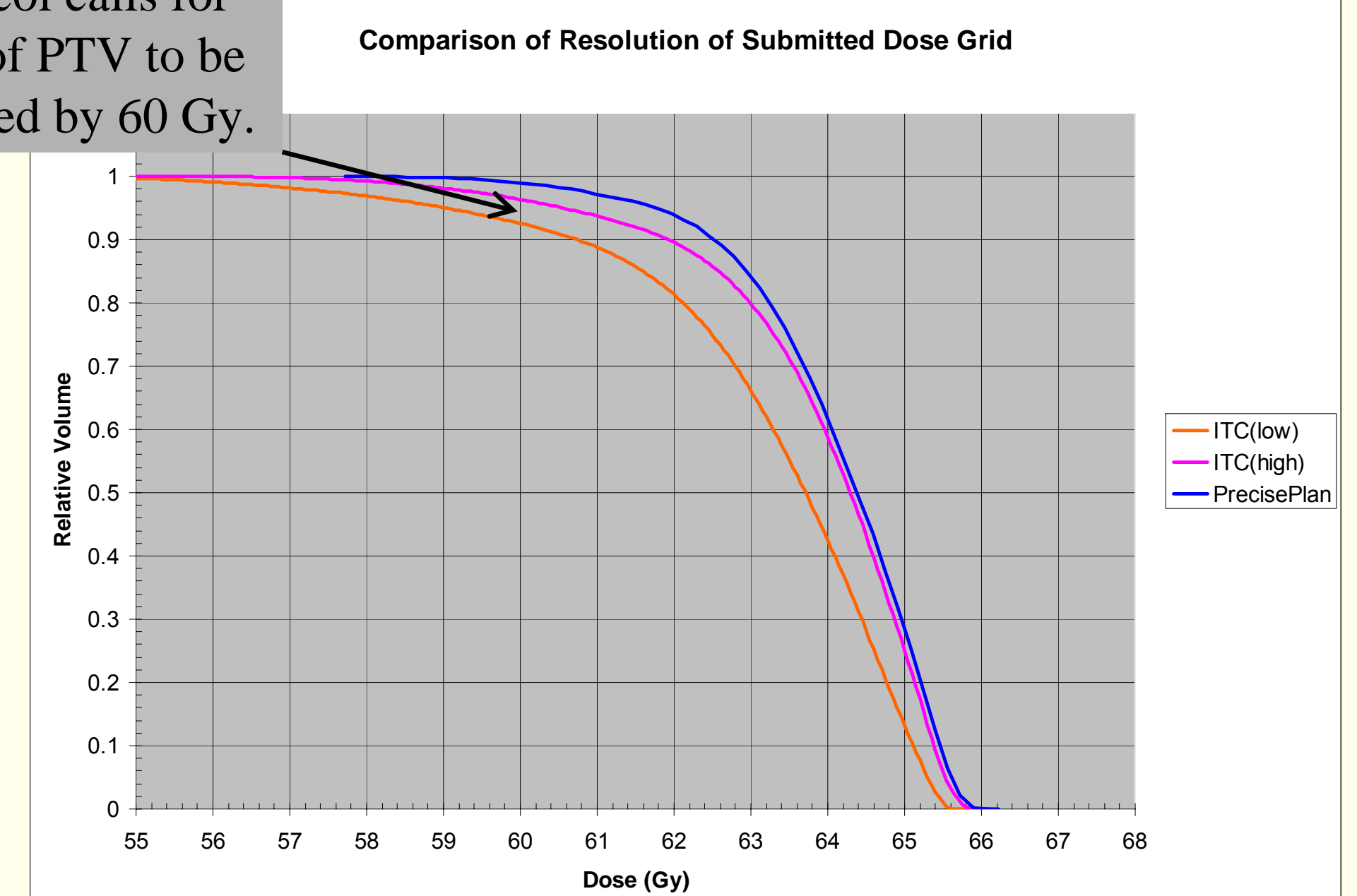

Fig. 4. Comparison of submitted vs. calculated DVHs for two different submissions to the ITC for a 5 mm (ITC(low)) dose grid and a 2 mm dose grid (ITC(high)). The dose resolution submitted has a large bearing on the calculated DVHs. The submitted DVHs (from Elekta PrecisePlan) are for an even higher resolution dose grid. The lower resolution DVH demonstrates a major variation according to the protocol, while the submitted DVH shows much better coverage.
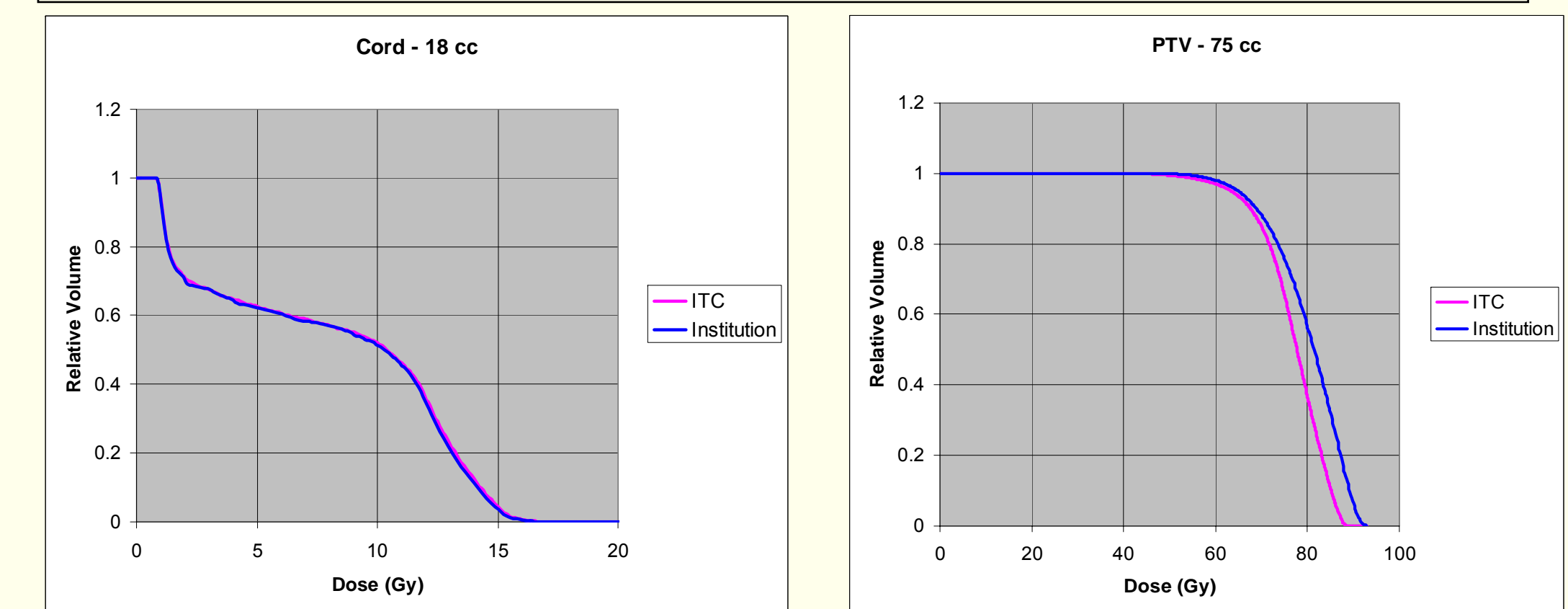

Fig. 5. Plots illustrating discrepancies between submitted DVHs and those calculated by the ITC for SBRT plans from a Philips Pinnacle treatment planning system. The differences are much more pronounced for the larger volume where there is a high dose gradient. The differences for the smaller volume spinal cord structure are negligible.

Discussion and Conclusions

Discrepancies among DVHs calculated by various commercial TPSs have long necessitated re-calculation of DVHs by the ITC for consistent correlation of dosimetry with outcomes. Re-calculating DVHs from submitted structure and dose distribution data achieves consistency in

1. the modeling of volumes defined by planar contours (i.e., how structure cross-sections are assumed to vary with axial distance), and
2. the interpolation of dose grid data to sample points in these volumes.

With increasing dose gradients, small variations in the modeling of volumes and the sampling of dose values can result in significant differences between dose coverage statistics reported by a treating institution and those computed for QA review. As a result, apparently protocol-compliant plans may be judged to violate QA criteria when submitted data are reviewed (fig 4).

By re-calculating of DVHs, the ITC also achieves consistency in
- DVH dose bin size,
- Geometric sampling resolution (voxel size),
- Naming of structures, and
- Logical combination of structures (combination of paired organs, exclusion of nested volumes, etc.) as specified in the protocol.

Our analysis of DVH discrepancies among various TPSs can help to set QA criteria for present and future protocols, especially those in which high dose gradients are required. This analysis should also allow us to develop guidelines for dose grid size and DVH calculation parameters of submitted digital data in advanced technology protocols.