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# The effect of voxel size on the accuracy of dose-volume histograms of prostate $^{125}$I seed implants

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Cumulative dose-volume histograms (DVH) are crucial in evaluating the quality of radioactive seed prostate implants. When calculating DVHs, the choice of voxel size is a compromise between computational speed (larger voxels) and accuracy (smaller voxels). We quantified the effect of voxel size on the accuracy of DVHs using an in-house computer program. The program was validated by comparison with a hand-calculated DVH for a single 0.4-U iodine-125 model 6711 seed. We used the program to find the voxel size required to obtain accurate DVHs of five iodine-125 prostate implant patients at our institution. One-millimeter cubes were sufficient to obtain DVHs that are accurate within 5% up to 200% of the prescription dose. For the five patient plans, we obtained good agreement with the VariSeed (version 6.7, Varian, USA) treatment planning software's DVH algorithm by using voxels with a sup-inf dimension equal to the spacing between successive transverse seed implant planes (5 mm). The volume that receives at least 200% of the target dose, $V_{200}$, calculated by VariSeed was 30% to 43% larger than that calculated by our program with small voxels. The single-seed DVH calculated by VariSeed fell below the hand calculation by up to 50% at low doses (30 Gy), and above it by over 50% at high doses (>250 Gy).
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Key words: prostate implants, dose-volume histogram, accuracy, dose grid resolution

## INTRODUCTION

Cumulative dose-volume histograms (DVH) are crucial in evaluating the quality of radioactive seed prostate implants. When calculating dose distributions and DVHs, the choice of voxel size is a compromise between computational speed (larger voxels) and accuracy (smaller voxels).

The American Brachytherapy Society recommends that dose calculations should be performed using a matrix resolution of 2 mm or less in an effort to minimize the effects of the large dose gradients inherent in a brachytherapy procedure, and to ensure adequate resolution of the reported parameters in the dose calculation.[1]

The accuracy in determining the fractional volume receiving at least a given dose decreases with increasing dose, as the volume gets smaller. The fractional volume of the prostate $V_{200}$ that receives at least 200% of the target dose (145 Gy) is the highest-dose reference criterion recommended by the American Brachytherapy Society[1] and the Radiation Therapy Oncology Group.[2] This volume is usually confined to the small, high-dose region in the immediate vicinity of each seed. When the accuracy of $V_{200}$ is ensured, the DVH is then accurate for all doses up to 200% of the target dose. The reduced accuracy at doses greater than 200% is deemed to be of minimal clinical significance.

We quantified the effect of voxel size in dose calculations on the accuracy of $V_{200}$, as well as $V_{150}$ and $V_{100}$. Furthermore, we retrospectively evaluated the accuracy of the DVH algorithm of VariSeed (version 6.7, Varian), a widely used treatment planning system, for five patient cases at our institution.

## MATERIALS AND METHODS

A seed dose calculation program based on the TG43 formalism[3] was written in MATLAB (The Mathworks, Inc., USA). In calculating DVHs, the proportion of each voxel's volume that lay within the structure was added to a bin of the DVH if the dose at the center of the voxel was larger than the bin's dose value.

### A. Single point source calculations

To confirm the accuracy of this program, dose calculations were performed with a point source approximation and the TG43 anisotropy constant. Since the isodose surfaces are spherical for a single point source, the DVH could easily be hand calculated.

The DVH of a single 0.4-U seed in a very large volume was hand calculated for doses between 20 and 800 Gy. This was compared to the DVHs calculated by our algorithm with resolutions of 0.1 and 0.5 mm, as well as by VariSeed with a 0.5 mm resolution (the finest resolution setting available on this system).

### B. Clinical calculations

In order to determine how small dose voxels should be to accurately determine $V_{200}$ in clinical plans, five patients who had received a prostate implant of $^{125}$I model 6711 seeds at our institution were randomly selected. The number of implanted seeds ranged from 96 to 118 (median: 104) and their air kerma strength was 0.4 U. The prostate volumes ranged from 33.2 to 48.3 $cm^3$ (median: 41.6 $cm^3$). The planned seed coordinates as well as preimplant prostate contours were obtained from our planning system files. The prostate volume was delimited by the contours imported from our treatment planning system. Each slice was taken to be a straight cylinder with a cross section defined by the contour on that slice, and a thickness of 5 mm (the spacing between ultrasound images).

For all patients, we calculated dose distributions with resolutions ranging from 0.5 to 5 mm, both with the calculation grid aligned with the seed implant planes, and offset by one-half voxel size in the *x*, *y*, and *z* directions. The corresponding values $V_{200}$ were calculated. For each patient, the average of the two values of $V_{200}$ (i.e., aligned and offset calculation grid) at the finest resolution (i.e., 0.5 mm) was taken as the reference $V_{200}$, and values at coarser resolutions (as well as values calculated by VariSeed) were compared to this standard. The root-mean-square (RMS) of the error over all patients was calculated. Similar calculations were performed for $V_{150}$ and $V_{100}$.

We also calculated the dose distribution for each patient using a calculation grid with a resolution of 1 mm in the *x* and *y* directions, and 5 mm in the *z* direction. The *z* coordinates of the calculation grid points coincided with the *z* coordinates of the seed implant planes at regular intervals of 5 mm. Using these dose grids, prostate DVHs were calculated, and compared with the prostate DVHs generated by VariSeed.

To further compare with VariSeed's DVH calculations, several DVH algorithms and voxel shapes were attempted.

## RESULTS

### A. Single point source calculations

For a single 0.4-U seed in a large volume, our DVH algorithm agreed with the hand-calculated DVH within ±1% for doses up to 300 Gy, and within ±3% for doses up to 800 Gy, when the resolution was 0.1 mm. At 0.5 mm resolution, the agreement is within ±5% at doses below 100 Gy, but becomes much coarser at high doses (Fig. 1). [When the seed is at the center of a voxel, the volume of the highest dose bin will be overestimated to be the volume of one voxel and the volume of the penultimate bin will be underestimated to be the volume of six voxels, etc. When the seed is at voxel corners, the volume of the highest dose bin is underestimated to be 0 and the volume of the penultimate bin is overestimated to be eight voxels, etc. Similar errors occur in lower-dose bins. Thus, each histogram differs from the true dose-volume curve (dashed curve in Fig. 1) by roughly the same amount, although they are staggered from each other.]

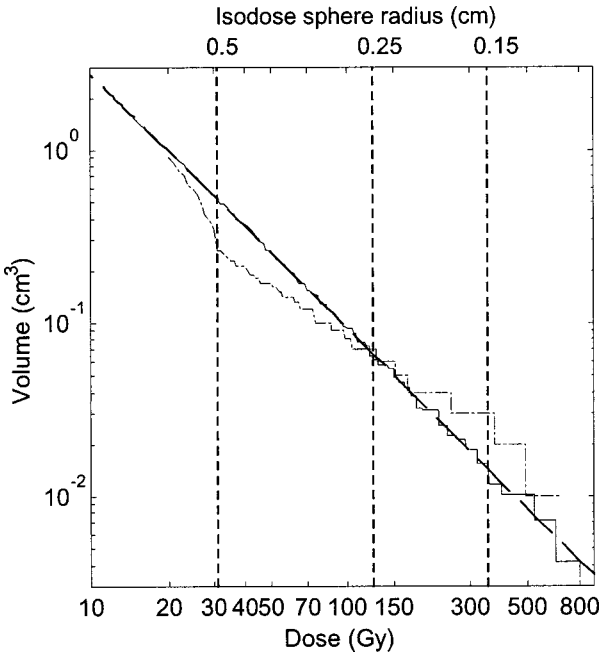


FIG. 1. DVH of a single 0.4-U seed: hand-calculated (dashed curve), VariSeed (dot-dashed), and our algorithm with a 0.5 mm resolution (solid curve). The DVH calculated with a 0.1 mm resolution is not shown, as it is indistinguishable from the hand-calculated curve. For better visibility, both axes are in logarithmic scale. The radius of the isodose sphere at three points of interest are indicated by vertical dotted lines.

The single-seed DVH calculated by VariSeed with a resolution setting of 0.5 mm underestimated the hand calculation at doses below 120 Gy (by as much as 50% at 31 Gy), and tended to overestimate it by over 50% at doses above 250 Gy.

### B. Clinical calculations

For all five patients, a resolution of 1 mm was sufficient to yield values of $V_{200}$ that were well within ±5% of the reference value [Fig. 2(c)]. (This reference value was taken to be valid, since values of $V_{200}$ at 0.5 mm resolution had a precision of 0.35%.) Resolutions finer than 1 mm yielded even more accurate values, while coarser resolutions rapidly gave rise to large errors (RMS of 27% at 2.5 mm resolution, and 69% at 5 mm resolution). The sign of the error was randomly distributed.

The values of $V_{200}$ calculated by VariSeed at 0.5 mm resolution, however, consistently exceeded our reference value at all resolution settings, by 30% to 50%.

The accuracy of the fractional volumes $V_{150}$ and $V_{100}$ was better than that of $V_{200}$ at any given voxel size, since these volumes are larger. Three-millimeter voxels were sufficient for ±5% accuracy of $V_{150}$ [Fig. 2(b)], while $V_{100}$ was accurate within ±1% for all voxel sizes up to 5 mm [Fig. 2(a)].

We were able to obtain good agreement with VariSeed's DVHs by using elongated rectangular voxels in our in-house algorithm. In this scenario, the dose is calculated with a fine resolution along each transverse seed implant plane, but not at all between these planes. Successive seed implant planes are separated by 5 mm in the *z* direction. When the resolution

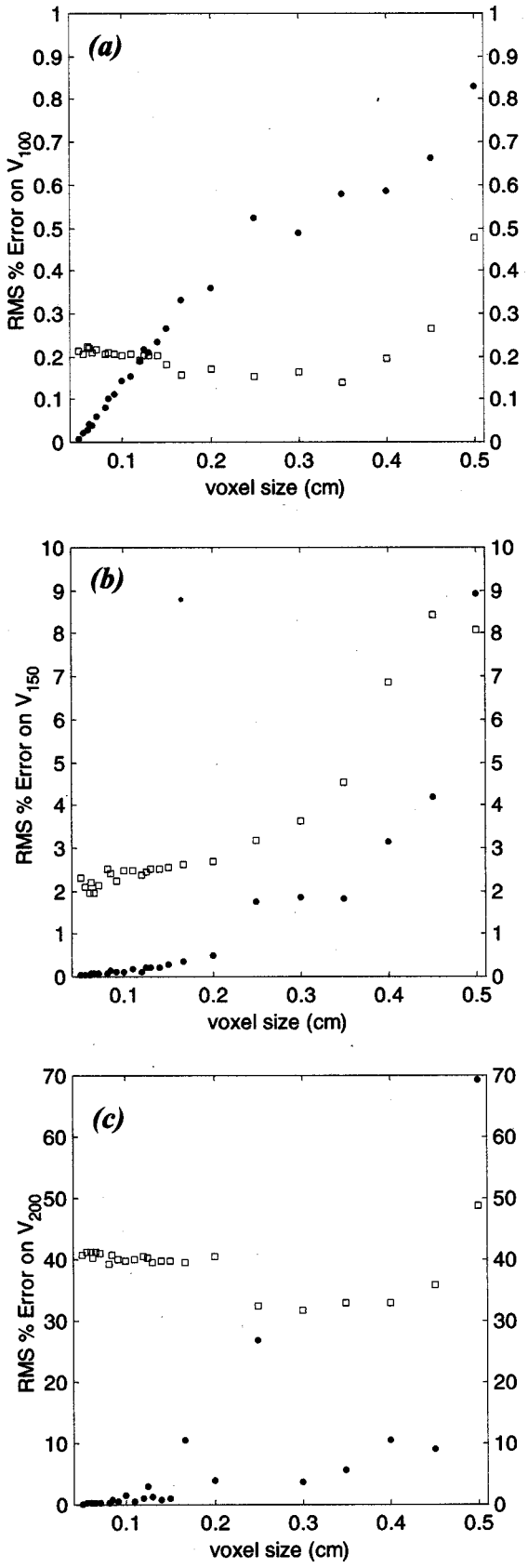


FIG. 2. The effect of voxel size on the accuracy of (a) $V_{100}$, (b) $V_{150}$, and (c) $V_{200}$. The RMS error is shown for VariSeed (squares) and our algorithm (dots). It should be noted that the scale is different for the three graphs.

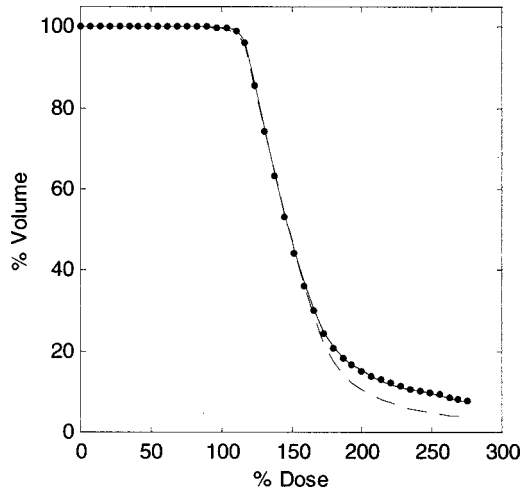


FIG. 3. DVH for one patient: $1\times1\times1\,\mathrm{mm}^3$ voxels (broken curve), $1\times1\times5\,\mathrm{mm}^3$ voxels (full curve), and VariSeed (dots).

setting is 1 mm, for example, the dose would be calculated with a 1 mm resolution in the $x$ and $y$ directions, but a 5 mm resolution in the $z$ direction.

To test the validity of the elongated voxel approximation for plans with various numbers of seeds, artificial plans were generated on VariSeed with a number of 0.4-U seeds ranging from 1 to 153, located in a rectangular box ($40\times40\times30\,\mathrm{mm}^3$). The DVHs calculated by VariSeed for these plans were compared to those calculated by our algorithm with both $1\times1\times1\,\mathrm{mm}^3$ and $1\times1\times5\,\mathrm{mm}^3$ voxels.

For all five patients, the DVH calculated using $1\times1\times5\,\mathrm{mm}^3$ voxels was almost identical to VariSeed's DVH with a resolution setting of 1 mm (Fig. 3). The same was true for the DVHs of artificial plans with a large number of seeds ($>45$) (Fig. 4). However, for artificial plans with a single seed or a small number of seeds ($<10$), the DVH calculated

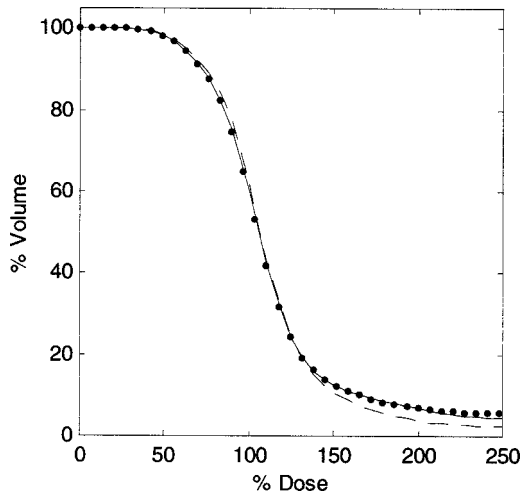


FIG. 4. DVH for an artificial plan with 69 seeds: $1\times1\times1\,\mathrm{mm}^3$ voxels (broken curve), $1\times1\times5\,\mathrm{mm}^3$ voxels (full curve), and VariSeed (dots).

using $1\times1\times5$ mm$^3$ voxels was not a good approximation of VariSeed's DVH, as it was significantly higher (by up to 80%) in the region near 100% dose.

## DISCUSSION

Dose calculations with a resolution of 1 mm in the *x*, *y*, and *z* directions yielded values of $V_{200}$ that were accurate well within $\pm5\%$, for the five patient plans examined. When computing the DVH of a single seed, however, a finer resolution was required ($<0.5$ mm), since the fractional volume contained by any given isodose surface is much smaller than for plans with a large number of seeds.

For a single 0.4-U seed, the DVHs calculated by VariSeed with a resolution of 0.5 mm fell below the hand calculation by as much as 50% at low doses, and above it by over 50% at high doses. For the five patient plans, VariSeed's values of $V_{200}$ exceeded ours by 30% to 43%.

The DVHs calculated with $1\times1\times5$ mm$^3$ voxels whose centers were coincident with seed implant planes were very similar to those calculated by VariSeed, for the five patient plans as well as for the artificial plans with a large number of seeds. However, discrepancies arose in plans with only a few seeds, indicating that VariSeed's algorithm applies further corrections to calculated volumes, which become significant when the volumes are small. The elongated voxels should nevertheless provide an excellent approximation of DVHs calculated by VariSeed for most patient plans.

## CONCLUSIONS

In prostate $^{125}$I seed implants, a dose grid resolution of 1 mm is sufficient to obtain DVHs that are accurate within $\pm5\%$ up to 200% of the target dose. The values of $V_{200}$ calculated by our algorithm were typically 25% to 30% lower than those calculated with the VariSeed DVH algorithm. We were able to obtain good agreement with VariSeed's $V_{200}$ (at the 1 mm resolution setting) by using voxels of *z* dimension equal to the spacing between successive seed implant planes ($1\times1\times5$ mm$^3$ voxels).

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[2] Radiation Therapy Oncology Group protocol 98-05: Phase II trial of transrectal ultrasound guided permanent radioactive implantation of the prostate for definitive management of localized adenocarcinoma of the prostate. http://www.rtog.org/members/protocols/98-05/98-05.pdf.

[3] R. Nath, L. L. Anderson, G. Luxton, K. A. Weaver, J. F. Williamson, and A. S. Meigooni, "Dosimetry of interstitial brachytherapy sources: Recommendations of the AAPM Radiation Therapy Committee Task Group No. 43," Med. Phys. **22**, 209–234 (1995).