TECHNICAL NOTE

Discrepancies in volume calculations between different radiotherapy treatment planning systems.

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Abstract

It has been determined that, contrary to expectation, there is a clinically significant variation in the volume calculations of different RTPS (Radiotherapy Treatment Planning System) for identical contours. The situation was investigated prior to a multi-centre trial[1] to determine whether tumour volume is an independent prognostic factor in NSCLC (non-small cell lung cancer)[2] and included four of the commercially available RTPS. The four RTPS tested were, Theraplan Plus V3.0, Cadplan V6.2, Focus V2.6 and ADAC V3.0. Five randomly chosen clinical target related volumes (3 GTVs, one PTV and one CTV) from the trial database originally marked on the Cadplan system were transferred to the other four systems and the resulting volumes were calculated. It was found that Cadplan consistently underestimated the volume relative to the other three systems by 6-12%. This systematic underestimation was found to be caused by different assumptions made by the Cadplan system about the axial outer slice extension of the volume. Cadplan truncates the volume, while the other three systems extrapolate it by half the slice thickness at each end. A short program was written to apply the same method of volume extension to the Cadplan volume that is utilised by the other systems. This produced calculated volumes that were within ±1.0% of the average of the volumes calculated by the other three planning systems, and the maximum deviation from the average for any planning system was then reduced to 1.5%. This program was implemented at all participating trial centres utilising Cadplan, thus reducing the inter-system variability to a negligible factor in comparison to the estimates of inter-physician variation[2]. This unexpected finding has significant implications for the validity of multi-centre trials using dose volume histograms, and indeed the adoption of any clinical protocol employing dose volume histogram constraints derived from experience at another centre employing a different RTPS.

Key words radiotherapy treatment planning, DVH, clinical trials

Introduction

When the potential variation in volume calculations between different planning systems was first canvassed as a possible source of systematic error in Trans Tasman Radiation Oncology Group (TROG) study 99-05, everyone instinctively expected that the variation between different planning systems would be insignificant in comparison to the already determined inter-physician variation[2]. Although some minor differences were expected, it was anticipated that there would be no difficulty in establishing that inter-system bias was a negligible factor, so that it could be safely ignored by the trial. The only point of initial discussion was how low the threshold should be set and it was initially agreed that ±1.5% was suitable.

It was decided to verify whether various planning systems to be used in the trial would return the same volume calculation when presented with an identical set of contours. The ADAC system, which the Peter MacCallum Cancer Centre did not have at the time, was compared with assistance from Queensland Radium Institute.

Method

Five clinical NSCLC patient target and associated volumes were outlined. The resulting contours, marked on a volumetric CT data set with 1 cm thick slices in accordance with the standard lung protocol at the time, were transferred from Cadplan to the other systems. Cadplan was used to generate the contours as it has the least image resolution, 256 x 256 pixels compared to the native 512 x 512 for the other systems. It was decided to generate the contours on Cadplan in order to be able to reproduce the contours generated on all the other three systems exactly. Also we

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Received: 10 September 2002; Accepted: 30 May 2003

were aware that the Cadplan calculation was geometric, and was determined completely by the vertex coordinates of the contour, whereas the other three systems used voxel based estimates of volume. By starting from the Cadplan system, we removed any effect due to the different image resolutions from the comparison. On the Cadplan system, a volume consists of a series of closed contours on each axial slice, the vertices of whicj must be on a pixel. It is possible to view, but not to edit, contours in the sagittal plane, as the sagittal view is simply calculated from the axial slice vertex coordinates. The contour co-ordinates were obtained from the header of the Cadplan CART (Cadplan Computer Aided Radiotherapy Treatment)[3] format CT image files, and then copied into the other treatment systems. This was done by a manual mouse input of tabulated co-ordinate values for the FOCUS system, while a digital transfer was possible to both Theraplan Plus and ADAC Pinnacle.

Once the systematic variation of the Cadplan system had been quantified a short menu based C[4] program using the resident compiler on the Cadplan system, called "TLA Cad", was written to read the contours and independently calculate an unbiased volume by a summation of areas[5], each area being calculated as a summation of triangles[6].

Results

The values shown in Table 1 are the raw data returned by the individual DVH applications supplied with each planning system. The values presented in Table 1 were normalised to the simple slab based volume calculation of TLA Cad. This is presented in Figure 1.

	Cadplan	Focus	TP+	ADAC	TLA Cad
1 GTV (8)	113	128	131	128	128
2 CTV (7)	195	209	210	209	210
3 PTV (10)	127	140	143	139	140
4 GTV2 (10)	219	233	238	233	233
5 GTV3 (10)	168	191	189	191	191

Table 1. *The raw data obtained from the planning systems used in the study. All volumes are measured in cubic centimetres. The number preceding the contour name is used to index the contour in figure 1. The number in brackets after the volume is the number of contiguous 1 cm thick axial CT slices on which the volume was defined.*

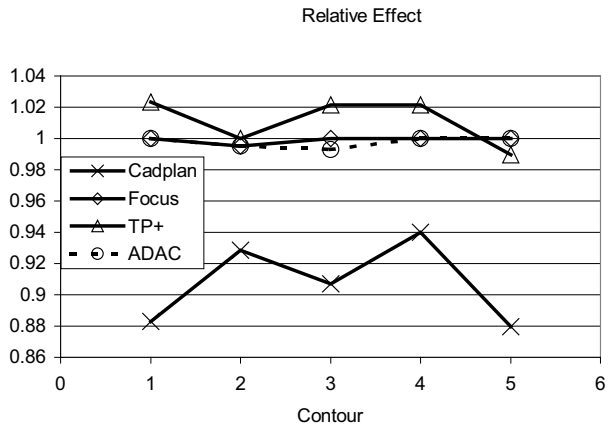

Figure 1. *To emphasise the relative difference between the different RTPS the results have been graphed relative to the simple slab based geometry volume calculation of TLA Cad.*

Discussion

After investigating the Cadplan volume calculation algorithm[7], it was determined that the reason for the discrepancy between the Cadplan and the rest of the planning systems was due to the extension of the limiting contours. For a given anatomical set of contours, three of the RTPS extend the volume calculation beyond the furthermost slice upon which it is marked and half way to the next. Cadplan terminates the volume calculation to what has been marked, with no extension. This was verified by entering simple geometrical shapes defined on single slices, Cadplan returned a volume of zero, the other systems returned a volume equal to the slice thickness multiplied by the area, showing that the simple contour was extrapolated axially by half a slice thickness in each direction. This is shown diagrammatically in Figure 2. Subsequent review of the clinical structures showed that it was possible to account for almost all of the variation due to this. In part to put this beyond doubt, and in part to correct for the systematic bias introduced by Cadplan to enable the trial to proceed, the separate program TLA Cad was written. The simple slab based volume calculation that it implemented, using the same extrapolation assumption of the other three planning systems, reduced the discrepancy between the systems to within the originally desired ± 1.5%. The facilitators of the previously mentioned trial[1] had previously determined the inter-clinician volume marking difference was, on average, 20%, but it was decided that it would be of benefit to the trial to remove the systematic bias introduced by Cadplan volume calculations. The program TLA Cad was therefore used to calculate volumes at all participating centres that had previously intended to report a volume calculated by Cadplan.

Although the discrepancies between TLA Cad and Focus, ADAC and Theraplan Plus are not clinically significant, they can be qualitatively understood through the different algorithms used by each system. Focus agrees most closely with TLA Cad, as both implement a slab based calculation. The only difference is that TLA Cad calculates the area of a contour on a slice by a summation of triangles, while Focus estimates the area by superimposing a grid and determining for each cell whether it is inside or outside the contour[8]. The ADAC volume calculation uses a summation of voxels, with "edge" voxels weighted to 50%[9]. This is essentially a slab geometry based method and would therefore be expected to be equal to or less than the Focus calculation in all cases due to the effect of off weighting the edge voxels. Finally the Theraplan Plus volume calculation algorithm[10] is also voxel based, but the default setting for the voxel size is much larger, and so the volumes estimated involve a

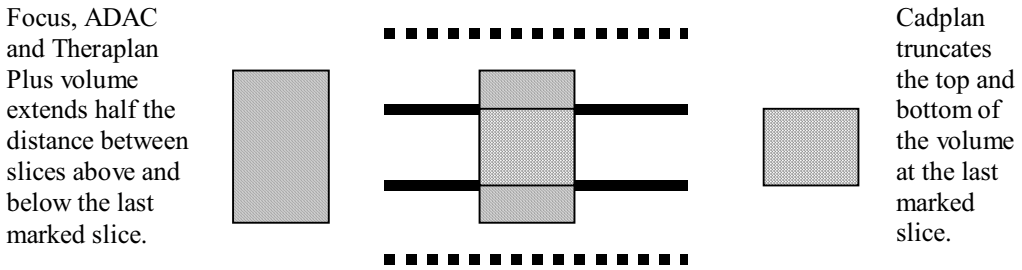

Figure 2. *Sagittal view of a prismatic volume defined on two contiguous CT slices.*

higher (although still clinically insignificant) random error, and the Theraplan Plus results are found further above and below the TLA Cad results than Focus and ADAC. Although Cadplan implements a geometric calculation of volume rather than a voxel based estimation, the clinically significant difference between it and the other three planning systems is not caused by systematic variations introduced by the voxel based assumption, because TLA Cad utilises a geometric calculation also, but has clinically insignificant disagreement with the results of the other three systems.

Conclusion

The above finding emphasises that it cannot be assumed that volume calculations from different RTPS will render the same result when given identical anatomy. This is important for many clinical trials as volume is the denominator for dose volume histograms, thus intercomparative analysis is questionable without a verification of the tools being used. In this case the effect occurred at the outermost slices which in many cases is the critical region for beam edge effects and expansion of critical organs, for example bladder and lung. The severity of the effect on DVH profiles and any associated tumour control calculations will vary from case to case, but differences in volume calculations alone, before the introduction of the added complication of dose calculation variations, have been shown to be significant in at least one clinically relevant situation. This study thus shows that full testing of planning systems is always necessary and especially so when collaborative trials are performed that use software provided by different manufacturers.

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