Comparison Between the Dose Distributions Calculated for Lung Cancer Patients Using Pencil Beam and Collapsed Cone Convolution Algorithms

Introduction: The initial patient plans were developed by Novalis's BrainSCAN treatment planning system which uses a pencil beam algorithm to calculate dose distributions. The plans were reevaluated using Pinnacle treatment planning system which utilizes a collapsed cone convolution superposition algorithm. Pencil beam dose calculation algorithms are commonly used in treatment planning systems. Although they are less accurate then mare sophisticated calculation algorithms they are fast and produce acceptable results when treating homogeneous media. However, the pencil beam method does not account for the increase in lateral electron scattering that occurs in low density target media such as lung tissue. The collapsed cone convolution method of dose calculation includes a primary term describing the energy loss of the primary photon beam or the total radiation energy released per unit mass (TERMA) and a convolution kernel term representing the energy deposited around a primary photon interaction site. The kernel term also describes the energy deposited by secondary particles in the volume elements around the primary photon interactions. Convolution of these values yields the dose distribution. In the convolution process the dose contributions from each irradiated volume element is calculated and the results are summed to get the total dose in the medium. Inhomogenieties and lateral electron transport are both accounted for in the calculation. The accuracy of this method is much better than that of an algorithm that does not account for these physical effects.

Plan Comparison: In order to reevaluate the patient plans initially the patient CT images needed to be recontoured in Pinnacle, ensuring that the volumes of each object of interest were equivalent to those used in the original plan developed on Novalis's TPS. The isocenter was then defined and the patient data was uploaded into Pinnacle. The dose distribution produced by BrainSCAN using the pencil beam algorithm was compared dosimetrically for several dose parameters to that produced by Pinnacle using its collapsed cone convolution algorithm.

Analysis: The DVH's produced by each TPS were analyzed. It is evident that a large volume of the PTV received less than prescription dose. The conformity index is defined as the ratio of the volume that receives 100% of the prescribed dose to the total volume of the target (PTV). There is a great reduction in the conformity index from the BrainSCAN plans to the pinnacle plans. The uniformity of the dose distribution inside the target volume is also very important in order to ensure that all of the diseased tissue is treated. The ratio of the minimum dose to the maximum dose delivered to the PTV in each case was calculated to determine the uniformity of the dose within the target volume. The average, maximum and minimum value of this ratio over all cases for each TPS was determined. There is a great decrease in uniformity of the of the dose distribution throughout the planned target volume from the original BrainSCAN calculation to the Pinnacle calculation. The average percent difference in the V_{95}, D_{100} and D_{50} values for the PTV of each patient plan calculated using the CCC algorithm was compared to the values from the plan calculated using the PB algorithm. Where V_{95} represents the volume of the PTV that received 95% of the prescribed dose and D_{100} and D_{50} represent the doses that 100% and 50% of the PTV received respectively. It can be seen that there is a major decrease in the volume that receives 95% of the prescribed dose according to CCC compared to PB. The range in these values is fairly small and indicates that in every case there was at least an 88% decrease in the volume that received 95% of the dose. There was also a considerable decrease in the dose received by 100% and 50% of the PTV. The mean and minimum dose delivered to the PTV according to each TPS was compared for each patient. The percent deviation in the mean and minimum PTV dose determined by the CCC algorithm was compared to that found using the PB dose calculation algorithm. The PB algorithm overestimates the dose delivered to the PTV. The mean dose was over estimated in every case except one and the minimum dose delivered to the PTV was overestimated by the PB algorithm in every patient plan. This is expected since the PB algorithm is not taking into account the lateral spread of electrons away from the beam axis. This lateral spread causes a decrease in central axis dose and ultimately results in an under dose in the target volume. The CCC algorithm is able to account for this affect and so consistently predicts a much lower dose to the PTV. The difference in dose distribution in the lung determined by each dose calculation algorithm was explored through a comparison of the mean lung dose (MLD) predicted by each method. The average percent increase in MLD from the BrainSCAN plans to the Pinnacle plans and the range in these values was determined. The MLD determined using the CCC algorithm was consistently much higher than that determined using the PB algorithm. The range in these values was very high with the lowest increase in MLD of 69.1% and the highest increase of over 800%. This is caused by the fact that some of the BrainLAB plans had calculated mean lung doses of close to or equal to zero making the ratio of the difference in MLD between the plans to the MLD from the BrainLAB plan approach infinity. The MLD typically increased from cGy to tens of cGy from BrainSCAN to Pinnacle. The great increase in MLD predicted by Pinnacle is expected since the PB algorithm does not accurately account for the increase in lateral electron scattering present in the low density lung tissue which results in an underestimation of the dose to the lung. The CCC algorithm takes this effect into account during its calculation and so its MLD is closer to the actual value which increases with the increase in electrons depositing energy in lung tissue rather than along the central beam axis.

Table I. The average, minimum and maximum ratio of the minimum dose to the maximum dose delivered to the PTV for the pencil beam and collapsed cone convolution calculation methods.

	PB	CCC
Average	.84	.38
Minimum	.35	.06
Maximum	.92	.69

Table II. Average % deviation in the V_{95}, D_{100} and D_{50} values computed using Pinnacles CCC dose calculation algorithm compared to those computed using BrainSCAN's PB dose calculation algorithm. The range in these values over all patients is also shown.

	Average	Range
V95	-97.1	-88.0 to -100
D100	-47.18	-24.5 to -63.7
D50	-24.80	-10.2 to -99.1

Table II. Average % deviation in the mean and minimum PTV dose values computed using Pinnacles CCC dose calculation algorithm compared to those computed using BrainSCAN's PB dose calculation algorithm. The range in these values over all patients is also shown.

	Average	Range
Mean PTV Dose	-8.27	1.18 to -24.81
Min PTV Dose	-54.45	-21.4 to -92.81