

# Monte Carlo and Ray Tracing Algorithm for treatment planning in clinical applications with Cyberknife

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**Introduction:** Accurate calculation of radiation behavior in a body is of crucial importance for the result of radiotherapy. Radiation planning systems work with algorithms to calculate the interactions between radiation and tissue. In this study Ray Tracing (RT) algorithm is compared to Monte Carlo (MC) algorithm in homogeneous and heterogeneous areas of the body for robotic stereotactic radiotherapy with Cyberknife<sup>®</sup>.

**Material and Methods:** In total 47 treatment-plans in head and lung area are used for this comparison. The dose prescription of the ten plans in homogeneous head area with target volume acoustic neuroma,  $n = 5$ , and brain metastasis,  $n = 5$ , was 13 Gy, respectively 18 Gy, on the enclosing 80 % isodose as radiosurgery. In heterogeneous thoracic region, plans were calculated for 20 lung tumors and 17 lung metastasis with 37.5 Gy, enclosing 65 % isodose, in three fractions (five days).

All plans were created using RT and were recalculated with MC, without any changing of planning parameters and plan-optimization. For each RT-MC-Plan pair, the absolute differences  $d$  of the parameters minimum dose ( $D_{min}$ ), mean dose ( $D_{mean}$ ), maximum dose ( $D_{max}$ ), dose of 2% ( $D_2$ ) and 98% ( $D_{98}$ ) of the target planning volume (PTV) and coverage (Cov, i.e. PTV volume / volume of the prescribed isodose) of the PTV were evaluated. Additionally, in thoracic region these parameters were calculated for the gross tumor volume (GTV). For each parameter, the distribution of RT-MC-dose differences in treatment plans is characterized by the minimum, maximum and mean value. For instance, for the mean dose parameter  $D_{mean}$  the symbols  $d_{mean}^{min}$  and  $d_{mean}^{max}$  denote the minimum and maximum value of the absolute differences. The average value, denoted by a bar, is equal to the difference of the mean values of the plans  $\bar{d}_{mean} = \bar{D}_{mean}^{MC} - \bar{D}_{mean}^{RT}$ . The percentage difference, if specified, is normalized to the value of the RT parameter, i.e.  $\bar{d}_{mean} = 100\% (\bar{D}_{mean}^{MC} - \bar{D}_{mean}^{RT}) / \bar{D}_{mean}^{RT}$ . Distribution and values of other dose parameters are denoted correspondingly.

**Results:** In heterogeneous thoracic region the average difference of the dose parameter  $D_{mean}$  is  $\bar{d}_{mean} = -16.73\%$  compared to the homogeneous head region with  $\bar{d}_{mean} = 2.73\%$ . Maximum deviations were found in thorax with  $d_{min}^{max} = -47.41\%$  and in head with  $d_{min}^{max} = -5.36\%$ . In addition, in thoracic region a dependency of  $D_{mean}$  on PTV size is recorded (Fig.1). This is also observed for the averages  $\bar{d}_{min}$ ,  $\bar{d}_{max}$ ,  $\bar{d}_{D_2}$ ,  $\bar{d}_{D_{98}}$  and  $\bar{d}_{Cov}$  of PTV. It was found that the coverage of GTV dropped slightly lower from 99.86 % to 97.7 % after MC recalculation in comparison to significantly more decrease of PTV from 98.14 % to 84.39 %.

A classification of tumor volume into three subgroups with 0-15 cm<sup>3</sup> (A), 15-30 cm<sup>3</sup> (B) and 45-60 cm<sup>3</sup> (C) shows that PTVs below 15 cm<sup>3</sup> have particularly high differences. In subgroup A the average difference between RT and MC regarding  $D_{mean}$  is  $\bar{d}_{mean}(A) = -20.31\%$  (-9.48 Gy). Subgroup B

shows on average  $\bar{d}_{mean}(B) = -11.79\%$  ( $-5.37$  Gy) and subgroup C  $\bar{d}_{mean}(C) = -9.25\%$  ( $-4.23$  Gy). The three subgroups can also be observed in dose differences  $\bar{d}_{min}$  and  $\bar{d}_{D98}$ , whereas the differences  $\bar{d}_{max}$  and  $\bar{d}_{D2}$  show only two subgroups with PTV sizes below  $15\text{ cm}^3$  and above  $15\text{ cm}^3$ .

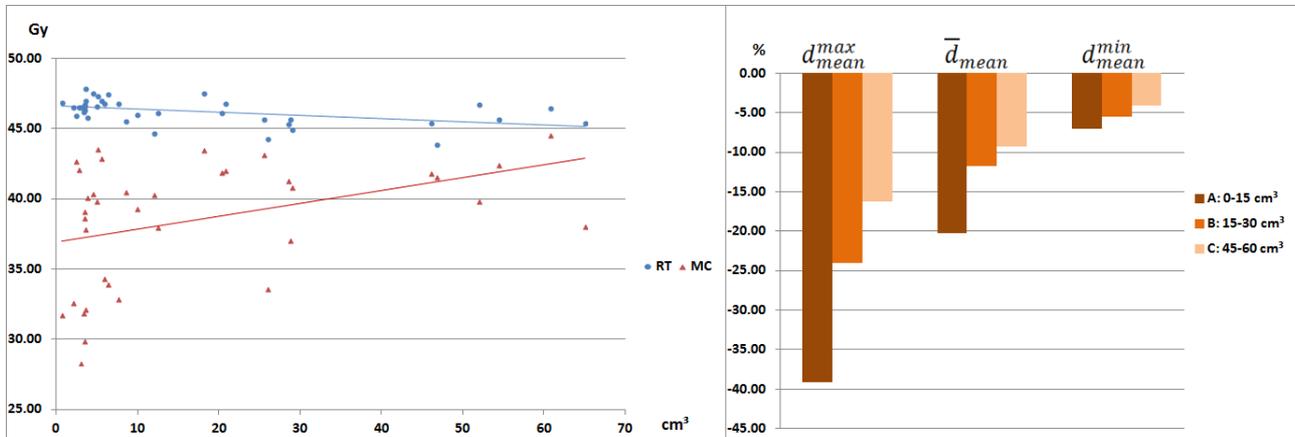


Fig.1: Comparison of the absolute  $D_{mean}$  (left) and the percentage difference (right) of PTV as a function of the PTV size in thoracic region. Small PTV size show greatest differences between RT and MC.

**Discussion and Conclusion:** It was shown that calculation algorithms RT and MC are equivalent within 5.36 % dose deviation in homogeneous body regions. Thus, in these body regions the use of RT is to be regarded as sufficient and appropriate [1]. In heterogeneous areas of the body, such as the thorax, however, there was a significant difference in dose distribution. In addition, the PTV volume has an effect on dose deviations. Similar dose reductions of 17 % in tumors with a diameter of less than 3 cm, 13 % in tumors between 3 cm and 5 cm, and a decrease by 8 % in tumors larger than 5 cm have been reported in [2].

$D_{min}$  and  $D98$  of the PTV are important parameters in order to avoid an under-supply of the lesion. However, these parameters show the highest dose drop, e.g.,  $d_{min}^{max} = -47.41\%$  after recalculation with MC. A decrease in PTV coverage from 97.7 % to 69.2 % after recalculation with MC has been published in [3]. In this study, the coverage decreased from 98.14 % to 84.39 %. Based on these results the prescribed fractionation of 37.5 Gy in three fractions to enclose 65 % isodose should be reconsidered. In [4] it is suggested to investigate 22 different treatment regimens with MC (15-72.5 Gy in 1 to 12 fractions) which were used in 45 studies.

In conclusion, differences in clinical outcomes may result from (i) whether the dose is prescribed for the GTV or PTV, (ii) to which isodose the dose is prescribed and (iii) the fractionation scheme. A uniform dosage is desirable to evaluate the clinical results in order to make further dose adjustments (if necessary). The necessity of the MC calculation in radiotherapy in heterogeneous regions, e.g. in the thorax, is clearly demonstrated by the results shown here.

### Literature:

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