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Dose Calculation Method Using Collapsed Cone Convolution for Clinical Photon Beam

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Introduction

Collapsed cone convolution (CCC) algorithm was first introduced by Anderson Ahnesjo, and its advantage is to reduce calculation time and to estimate more accurate dose distribution in heterogeneous media compared to convolution/superposition method[1]. To calculate dose distribution using TERMA(total energy released per media) and kernel, this algorithm assumed several tens of collapsed cone lines from origin voxel. Deposited dose at each voxel traversed by each cone line was assumed to be concentrated from its surrounding voxels. Since effective path length is used along the collapsed cone lines with from directions, it can estimate dose contribution from lateral scattered radiation more accurately in the heterogeneous media.

We implemented collapsed cone convolution algorithm for treatment planning system considering the effect of photon energy spectrum, beam hardening effect, kernel tilting effect, and various parameters for shape of beam profiles.

Materials and methods

The energy spectrum of photon beam was decided using auto-optimization process based on measured percent depth. Kernel distribution that represented energy spread function from the center of TERMA was constructed using TERMA weighted energy fluence and published mono energy kernel data(from 100keV to 50 MeV).

TERMA distribution at the specific conditions of radiation treatment was calculated. In detail, fluence map at specific field shape was defined by the shape of radiation field. And the volume of ROI(region of interest) was set to 50 x 50 x 50 cm3 with 5 mm's resolution. TERMA at each voxel was calculated as below calculation:

$$TERMA = \sum_{allE} I_{Init} \times Open\_ratio \times \left(\frac{d_{ref}}{SVD}\right)^2 \times f_{horn} \times \exp\left(-\frac{\mu}{\rho}(E) \times f_{soften} \times d_{eff}\right) \times E \times \frac{\mu}{\rho}(E)$$

where, I_{Init} is initial fluence, *Open_ratio* is the transmission ratio through jaw or MLC, d_{ref} is a reference depth (SSD = 100 cm), SVD is source to voxel distance, f_{horn} is horn effect with off axis distance, f_{soften} is beam softening effect near beam center, d_{eff} is effective depth using density scaling, and $\mu/\rho(E)$ is mass attenuation coefficient at energy E. We also considered the effect of finite source size using Gaussian blurring.

Collased cone lines from an orign voxel were

assigned equally into 8 azimuthal angles(ϕ) and 12 zenithal angles(Θ. The range of calculation for each kernel array was set up to 8 cm with 0.3 cm's resolution. Voxel lists traversed by each collapsed cone lines were extracted using lay-search method. The dose at each voxel was determined by the summation of all contributed kernel values from each collapsed cone lines as below equation:

$$D(\vec{x}) = \sum_{\Omega=1}^{96} D_{sub}^{\Omega}(\vec{x}-\vec{r})$$
$$= \sum_{\Omega=1}^{96} TERMA(\vec{r}) \cdot \left[k_{primary}^{\Omega}(\vec{x}-\vec{r}) + k_{scatter}^{\Omega}(\vec{x}-\vec{r})\right] \cdot \rho(\vec{r})\Delta V$$

where D_{sub} is the contributed dose from cone line Ω, $k_{primary}$ and $k_{scatter}$ are primary and scatter kernel values from vector $\boldsymbol{r}$ to vector $\boldsymbol{x}$.

Resutls

Calculated percent depth doses and dose profiles at 10 cm's depth with various field sizes are show at Figure 1 and Figure 2. All calculated PDDs were well agreed with measured data except near the build-up region. Under-estimation at build-up region and the shift of d_{max} were caused by non-considering the dose from electron contamination. The results of dose profiles showed good agreement with measured data under 10x10 field size, but some inconsistency at penumbra region were appeared at more than 20 x 20 field size.

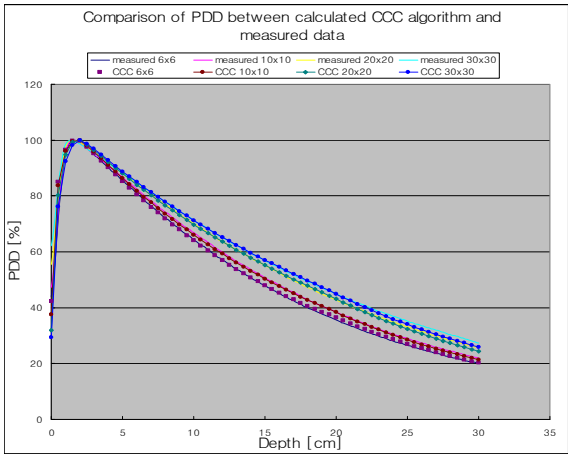

Figure 1. Comparison of PDD between calculated CCC algorithm and measured data

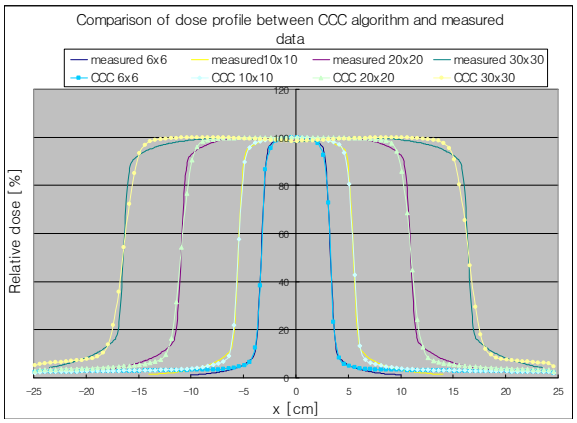

Figure 2. Comparison of dose profile between CCC algorithm and measured data

Conclusions

In this study, we presented practical method to implement collapsed cone convolution algorithm. Calculated results by our implemented algorithm were well agreed with measured dose at small field size (< 20 x 20 cm^2). The inconsistency near build up region was caused by the dose of electron contamination, and we will be also add the model to compensate this dose errors. At the large field sizes, kernel based superposition/convolution model seems not to explain the increased dose ratio with increased field size. This is because contributions by kernel from far sites have little contributions to the dose, and the radius of kernel is practically limitted at the cost of increasing the performance of calculation time in TPS. Our next study will be progressed to compensate theses inconsistencies.

Reference

[1] Anders A, 1989 Collapsed cone convolution of radiant energy for photon dose calculation Medical Physics 16(4) 577-592