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論　文　内　容　の　要　旨

〔　題　　名　〕Monte Carlo Applications in High-Precision Radiation Therapy
（高精度放射線治療へのモンテカルロ法の応用）

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This study demonstrates some remarkable applications of MC dose calculation algorithm in high-precision radiation therapy treatment planning and quality assurance. The goal of this dissertation is to improve the implementation of MC dose calculations in modern external beam radiation therapy.

Dose in radiation therapy has been reported as the water-equivalent dose using conventional dose calculation algorithms. The MC algorithm employs characterization of human tissues by elemental composition and mass density. It enables more accurate dose calculation for radiation therapy treatment planning and typically reports absorbed dose to medium. Whether one should use dose to medium or tissue (D_m) in place of dose to water (D_w) for MC treatment planning remains the subject of debate.

The first aim of this study is to evaluate the differences between dose-volume indices for D_m and D_w MC-calculated IMRT plans. The IMRT optimization and MC calculations is performed using the iPlan RT Dose™ ver 4.1.2 (Brainlab, Munich, Germany) treatment planning system (TPS) with an X-ray Voxel Monte Carlo (XVMC) dose calculation engine. D_w and D_m results for target and critical structures are evaluated using statistical analysis.

Our study demonstrates that employing D_m in place of D_w in MC-calculated IMRT treatment plans introduces a significant systematic difference in target DVHs. We recommend that for diffused target structures (such as spine tumors), dose to water is a better quantity for dose prescription in photon beam treatment planning using existing MC TPS. While for critical structures, it would be reasonable to report D_m always. However in future with the availability of finer spatial resolution, D_m will be the most suitable variable for both target and critical structures' dose prescription and reporting in MC treatment planning.

Technical developments in radiotherapy (RT) have prompted the need for systematic quality assurance (QA) to ensure that clinical institutions deliver prescribed radiation doses consistent with the requirements of clinical protocols. As an

essential part of QA, an ideal dose verification system should be independent of the treatment planning system (TPS). As a second aim of this dissertation, a MC based standard LINAC model is developed for independent verification of dose distributions and reproducibility evaluation of the developed model has been performed. The BEAMnrc MC code is used for the characterization of the 6, 10 and 15 MV photon beams for a wide range of field sizes. The modeling of the LINAC head components is based on the specifications provided by the manufacturer. MC dose distributions are tuned to match Varian Golden Beam Data (GBD). For reproducibility evaluation, calculated beam data is compared with beam data measured at individual institutions. An MC-based standard LINAC model developed to independently verify dose distributions for QA of multi-institutional clinical trials and routine clinical practice has proven to be highly accurate and reproducible and can thus help ensure that prescribed doses delivered are consistent with the requirements of clinical protocols.

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論文審査の結果の要旨及び担当者

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論文審査の結果の要旨

This study demonstrates some remarkable applications of MC dose calculation algorithm in high-precision radiation therapy treatment planning system (TPS) and quality assurance (QA). The goal of this dissertation is to improve the implementation of MC dose calculations in modern external beam radiation therapy.

Dose in radiation therapy has been reported as the water-equivalent dose (Dw) using conventional dose calculation algorithms. The MC algorithm employs characterization of human tissues by elemental composition and mass density and typically reports absorbed dose to medium (Dm). Appropriate dose prescription to the target volume containing different biological media using Dm or Dw is a significant issue.

The first aim of this study is to evaluate the differences between dose-volume indices for Dm and Dw MC-calculated IMRT plans using the iPlan RT DoseTM with an X-ray Voxel Monte Carlo (XVMC) dose calculation engine. Our data shows that for the target cells with a diffused pattern in bony anatomy, Dw can be higher by ~ 5% compared to Dm. This is due to the fact that high density bone causes a higher fluence of secondary electrons in the water cavity and consequently a higher dose is deposited compared to the case of the cavity filled also with bone. Dm represents average dose within the whole voxel. For cells embedded in heterogeneous tissues, the accuracy of computed dose is strongly affected by the size of internal MC dose computation grid and the uncertainty of CT number to medium-type conversion. Tumor cells embedded within a medium are more water-like than medium-like and dose within soft tissue cells surrounded by bone material is reflected accurately not by Dm, but by Dw.

In conclusion, this study revealed that for diffused target structures (such as spine tumors), Dw is a better quantity for dose prescription in photon beam treatment planning

using existing MC TPS, and Dm will be the most suitable variable for both target and critical structures' dose prescription under finer spatial resolution reporting in the future MC TPS.

Technical developments in radiotherapy (RT) have prompted the need for systematic QA of multi-institutional clinical trials to ensure that clinical institutions deliver prescribed radiation doses consistent with the requirements of clinical protocols. MC algorithm is most suitable for the verification of dose distributions in a patient. As a second aim of this dissertation, a MC based standard LINAC model is developed for independent verification of dose distributions and reproducibility evaluation of the developed model has been performed. The BEAMnrc MC code is used for the characterization of the 6, 10 and 15 MV photon beams for a wide range of field sizes. The modeling of the LINAC head components is based on the specifications provided by the manufacturer. MC dose distributions are tuned to match Varian Golden Beam Data (GBD) very accurately. To further substantiate the capability of the developed model, reproducibility evaluation has been performed by comparing the MC beam data with beam data measured at individual institutions.
In conclusion, this study demonstrated the potential of the standard LINAC model as a pivotal tool to ensure that participating institutions deliver prescribed doses that are consistent with the requirements of clinical protocols and to validate the outcomes of clinical trials.

These findings are significant outcomes with application of MC dose calculation algorithm in high-precision radiation therapy TPS and QA.
The study sufficiently fulfills the requirements for a PhD degree.