IMRT OPTIMIZATION

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Optimized radiotherapy planning is the basis of intensity-modulated radiation therapy (IMRT) because this type of planning invariably results in specifying intensity distributions that are non-uniform. Radiotherapy optimization is often called "inverse" planning to imply that the desired dose distribution is input to the calculation and the intensity pattern is the output. In fact, most methods are actually iterative in nature in that the optimal solution is searched for from a set of feasible ones.

The results depend on the objective function guiding the search, the constraints placed on the search and the type of "search engine" used. The objective function is a function, or more generally an operator on the dose distribution and a descriptor of the regions-of-interest, which results in a single scalar value characterizing the quality of the solution. Both physical and biological objective functions have been used. A least-square sum of the deviation between the desired and actual dose distributions is an often-used physical objective function. The probability of uncomplicated control, using several biological models of tumor control probability and normal tissue complication probability, has been used as a biological objective function. Physical objective functions are currently more trusted but biological objective functions may ultimately be a better figure-of-merit for the solution when there are better biological bases for the models.

Constraints specify values of dose or intensity that are allowed. For example, the intensity pattern must have only positive values. The search for the best solution must be confined within the bounds of the constraints. If constraints are too tight no solution may be possible. Instead of constraints, penalty terms may be introduced into objective functions so that unfeasibility does not result. Dose-volume "constraints" have often been implemented as penalty functions.

Search engines are generally classified into stochastic methods, such as simulated annealing or the genetic algorithm, and deterministic methods like the gradient descent or maximum likelihood methods. Stochastic methods are capable of finding a global minimum of an objective function (but are only guaranteed to for infinite calculation times) but deterministic methods may be quicker, and for many problems, find solutions which do not appreciably differ from the global minimum or are not needed because there is only one minimum. On the other hand, problems such as determining the best beam directions to use or some types of biological objective functions have been shown to result in a multitude of local minima. It is possible to have solutions which, in effect, tighten up constraints so that the search space becomes progressively reduced.

The character of the optimized solution depends on many factors. Some objective functions result in higher dose uniformity in the target volume. Increased dose uniformity in the target volume usually results in higher dose to sensitive structures. Increasing the number of beam directions results in better uniformity and lower maximum dose to normal tissue but the improvement becomes asymptotic. Cases that include the presence of a complex target volume along with sensitive structures that are adjacent to the tumor can benefit the most from larger numbers of beam directions and highly-modulated high-resolution intensity patterns. Coplanar beams are usually used for IMRT below the head because the optimization results suggest that there are limited additional benefits resulting from the use of non-coplanar IMRT fields and the selection of optimal field directions expands the solution space substantially. When sufficient numbers of beams are used the beam orientation become less important and an odd number of equally spaced beams are typically used.

The field of radiotherapy optimization is young. As computer speed and memory increases, search parameters such as beam energy, beam type, treatment fractionation, and the impact of setup error and organ motion will be included in the objective function or constraints. Search techniques borrowed from other field such as economics will be implemented. It is likely that optimization and IMRT will have an impact on the field of radiotherapy comparable with that of megavoltage beams.

Educational Objectives

1. To be introduced to IMRT optimization.
2. To understand the relationship between objective functions, constraints, and solution search methods.
3. To see examples of the capabilities and limitations of IMRT optimization.
4. To look into the future of radiotherapy optimization.

TRM and PJR have financial interest in TomoTherapy Incorporated which is participating in the commercialization of tomotherapy.