Correspondence

Comment on "Quantifying the interplay effect in prostate IMRT delivery using a convolution-based method" [Med. Phys. 35, 1703–1710 (2008)]

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To the Editor,

In the May issue of *Medical Physics*, Dr. Li *et al.*[1] investigated an important implication of the philosophical difference between IMRT and conformal radiotherapy, i.e., that each conformal radiotherapy beam fully encompasses the target volume while some or all segmental IMRT's segments each irradiate only a partial volume. Each target voxel is meant to receive the prescribed dose when summed over all segments and all beams. But this requires that the elements of the plan be superimposible, i.e., that the superposition theorem of linear system theory can be applied. Application of the superposition theorem requires that the patient treatment system have the properties of linearity, causality, and time-invariance. Dose linearity[2] can be undermined by temporal fragmentation of a plan into many small-MU segments, but with management of this fragmentation, adequate linearity can be assured. Causality, i.e., the expectation that patient dose results only from an applied treatment, is limited by the incidental dose resulting from localization imaging,[3] but with good management of this imaging dose, an assumption of causality is also justified.

Time-invariance, on the other hand, rests on the assumption of a fixed and rigid target, an assumption that often is not justified. Because actual intrafraction motion always acts to degrade the target dose distribution, failures in the time-invariance condition are of particular interest to Li *et al.* To investigate the degradation of dose distribution as a result of intrafraction motion, these authors convolved measured intrafraction patient motion patterns with the expected time-dependence of planned dose deliveries.

Their valuable work, however, also points to the importance of robustness as a goal in teletherapy prostate planning. A plan's robustness, defined qualitatively, is its insensitivity to unexpected deviation from the assumptions of the model and this is a property not naturally reflected in a dose-volume histogram. But, it is important both in terms of patient motion and in terms of equipment performance. For example, a treatment plan that uses many small-MU segments would be less robust to an accelerator's performance than a plan that uses only few large-MU segments because a small degradation in system performance would result in a larger degradation of the delivered dose distribution. Likewise, planning to treat a pair of abutted fields using a common isocenter and asymmetric jaws would be more robust to patient setup than a plan to use two symmetric fields aligned on different isocenters. In the dual-isocenter case, a small setup error would result in a much larger deviation from the planned dose distribution than would result in the single-isocenter case. Also, the significance of individual leaf-tip position errors, as investigated by Litzenberg[4] *et al.*, will be quite different if the leaf-tip is at the edge of a treatment margin, as in CRT, than if it is in the middle of the tumor, as in IMRT.

Robustness is a general advantage of a simpler plan over a more complex alternative, because the simpler plan will tend to minimize the effect of deviations from the planning model on the delivered treatment. Consider that in conformal treatment planning, we would never intentionally abut four 5×5 fields to treat a 10×10 region. Likewise, we would never intentionally deliver a 99-MU conformal field in 3-MU increments. Yet, these are exactly the sorts of strategies that define IMRT planning. Intuition tells us that intentional spatial and temporal fragmentation is unacceptable in conformal radiotherapy, even when the DVH does not make this fact apparent. Likewise, our intuition should tell us that fragmentation is undesirable in IMRT planning, and should be accepted only to the extent that this fragmentation creates offsetting benefits, which cannot be otherwise achieved. Consider also that in IMRT, the role of beam penumbra is much greater than is its role in conformal radiotherapy since much of the dose delivered to many of the IMRT target voxels is delivered through penumbra. This is in contrast with conformal treatment, where only the target periphery is treated with penumbra. Because an accelerator's penumbra is optimized for treating the margin while its umbra is optimized for treating the target itself, the extensive in-field role that penumbra takes on in IMRT is not inherently desirable, even when it is acceptable. In practice, the added complexity, added uncertainty, as well as the added cost, introduced by using IMRT delivery instead of simpler conformal delivery are acceptable because the treatment advantages made possible by segmental IMRT instead of simpler conformal delivery generally more than justify these disadvantages. However, in comparing an IMRT plan to a competing conformal plan, or even more importantly to a simpler IMRT plan, frag-

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mentation and other forms of heightened complexity should be weighed as inherently undesirable negative characteristics. All else being equal, the simpler plan is the superior plan.

In an optimal IMRT prostate plan, most or all of the target voxels will receive at least some dose from each beam. Analogous to the zero-frequency, "dc" component of an electrical signal, this optimal plan can be said to have a significant zero-frequency "conformal" component. There does not exist a mathematically unique solution to the prostate treatment-planning problem of achieving an optimal dose distribution, as characterized by the DVH. Lacking a unique solution, we therefore pursue a sensible optimization path. Based on reasons including robustness, we should always pursue a solution path that naturally tends to minimize the spatial and temporal fragmentation, i.e., the spatial and temporal bandwidth, and tends to maximize the zero-frequency conformal component. Maximizing the conformal component will minimize the role of midfield penumbra, minimize the segment interplay effect, and maximize robustness. Dose delivery efficiency (prescribed dose/aggregate MU) correlates with maximization of the conformal component in a treatment plan. Thus, a plan's quantitative dose delivery efficiency can often be used as a surrogate for its qualitative conformality. The notion of segregating the conformal component of a plan from its modulated component has been used to advantage in the past. The universal wedge[5] synthesizes an arbitrary wedge angle by placing a single, steep-angle, metal wedge into a treatment field during only part of its delivery. The Dynamic Wedge was an early and simple form of dynamic beam modulation. In developing the Dynamic Wedge into the Enhanced Dynamic Wedge[6] (EDW), the approach of isolating the conformal component was also applied to advantage when the EDW field was temporally split into an open-field phase and a jaw sweep phase. More recent work on the separation of the modulated component of an IMRT plan from its nonmodulated component has called this approach hybrid IMRT.[7]

In typical IMRT prostate planning, multiple nonrotating fields are distributed evenly across the planned angular range. Maximizing the number of fields maximizes conformance of the dose distribution onto the target (a desirable planning characteristic) but the number of fields is limited by the institution's tolerance. The authors, in this case, selected seven fields. Interest in the use of very many treatment angles to improve dose conformality has fueled recent work in intensity modulated arc therapy (IMAT), which promises increased complexity by adding yet another degree-of-freedom to the treatment planning process.

Building an IMRT prostate plan, instead, around an anterior conformal hemiarc (ACHA) naturally maximizes the conformal component of the plan, maximizing robustness, and minimizing the segment interplay effect. Additionally, it maximizes conformality, produces excellent critical structure sparing, improves throughput, reduces equipment wear, and makes every segment of every beam intuitively sensible to the person designing the plan. These would seem like important factors to anyone who would contemplate the importance of the segment interplay effect.

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