Correspondence

Task Group 76 Report on ‘The management of respiratory motion in radiation oncology’ [Med. Phys. 33, 3874–3900 (2006)]

(Received 6 October 2009; revised 19 October 2009; accepted for publication 19 October 2009;
published 24 November 2009)
[DOI: [10.1118/1.3260838](https://doi.org/10.1118/1.3260838)]

To the Editor,

In 2006, the AAPM Task Group 76, on respiratory motion in radiation oncology, produced a generally very useful report.¹ Mostly in Sec. V.C of this report, an “interplay” issue between motion from the MLC leaves in *dynamic* IMRT (such as sliding jaw, tomotherapy, and types of VMAT, for example) and organ (or tumor) motion is considered. However, the clinical implications for such interplay, or perhaps more precisely termed “interference,” are somewhat minimized based mainly on fraction averaging considerations. These implications are specifically minimized in the discussion of the effects of the 5 mm criterion that is to be used for the central decision of whether motion management should be used. We believe that this criterion should be expanded to include a consideration of the frequency coherence between the fluence modulation and the tumor motion. The fluence modulation pattern is unique to any particular modality and may vary between treatment plans. The current 5 mm criterion includes only the tumor motion amplitude; essentially, it is based on the assumption that this factor always dominates, and it may not have been evidence-based to a high enough degree. In addition, the effects of fractionation are very likely to reduce dose errors, but as stated in Sec. V.C,¹ one should not rely on fractionation alone.

Evidence for a potentially dominant role for frequency dependence comes from recently published helical tomotherapy² experiments. In Fig. 4 of Chaudhari *et al.*,³ there is a breathing motion displacement graph with each breathing cycle depicted along with the “moving average.” The moving average is nothing more than the low frequency component (“drift”) of the breathing. That drift, about 5 mm in extent for the 15 mm scaling overall, leads to a significant dose error³ (>10%) in Fig. 5. However, the much larger and much higher frequency, main breathing displacement of 15 mm leads to very small dose errors within the PTV (note that the shift in Fig. 5 must have been due to the registration at a position other than the time average of the motion). The reason why these low frequency drifts have such a big effect is because the power spectrum of the total motion is overlapping the response function for interference with the tomotherapy couch movement through the beam (see Fig. 1 of Kissick *et al.*⁴). When the breathing motion through the tomotherapy beam is made regular and without drifts such that the motion probability distribution function is invariant in time, then one will simply get blurring (see Fig. 12 of Kissick *et al.*⁴). This result demonstrates that only blurring is possible when the frequencies of the MLCs are very different

than the frequencies of the tumor motion. The 1 cm motion of that Fig. 12 created no noticeable dose errors relative to the 2.5 cm beam smearing that happens without motion. This is direct evidence that the amplitude of the tumor motion alone *cannot* always predict whether a large dose error will occur—one also needs to consider the interaction with the frequency or time behavior of the fluence modulation. While this work was done experimentally using helical tomotherapy, all dynamic IMRT will have this issue.

Another way to look at this issue is to refer to the often reproduced Fig. 1 in Bortfeld *et al.*⁵ The two phases (two stars) in the figure would get the same dose difference even if the tumor motion amplitude was made either smaller or larger. By contrast, if the frequency of the voxel movement was either very fast or very slow compared to the leaf motion, then there would be much less dose difference between the stars; therefore, no phase dependence and no interference, only blurring. In Fig. 3 of Kissick *et al.*,⁶ one can see the effect of interference diminish from Figs. 3(f)–3(d) as the beam width divided by the couch velocity becomes much longer than the breathing period. One can also see that the blurring increases to its maximum [edge behavior of Fig. 3(d)] as the interference and phase dependence diminish. Therefore, theoretically, we also see that the dose error depends not only on the amplitude of the tumor motion, but it can easily be dominated by the frequency dependence near interference. Unfortunately, for simplicity, the time dependence of the dose rate is neglected in Bortfeld *et al.*,⁵ which means no analytical interference calculation is possible to properly simulate a dynamic IMRT situation like their illustration of Fig. 1 [see Sec. II.B after Eq. (8)].

The following argument should extend beyond helical tomotherapy into all forms of dynamic IMRT. The dose D at a voxel at position $\vec{x}$ can be formulated as a beamlet-filtered dwell time (fluence),

$$D(\vec{x}) = \int_{-\infty}^{\infty} T(\vec{x}') B(\vec{x} - \vec{x}') d\vec{x}', \quad (1)$$

and the T is the total “dwell time” (units of fluence) convolved with the beamlet profile B .

$$T(\vec{x}') = \int_0^{\infty} R(t) \delta(\vec{x}' - \vec{x}_{\text{motion}}(t)) dt, \quad (2)$$

where the time-dependent modulation is $R(t)$ and inside the Dirac delta function is the time-dependent tumor motion displacement function, $\vec{x}_{\text{motion}}(t)$. This formulation is simply a

generalization from the original investigation on this topic [see Eq. (7) of Yu *et al.*⁷]. A key feature for a relatively high frequency tumor motion is that the total dwell time stays nearly constant from voxel to voxel in the PTV, as is the case with nearly regular breathing in helical tomotherapy. The frequencies at which blurring becomes interference will vary from one IMRT modality to another, but the same physics principles will apply to any dynamic IMRT modality. The specific criteria of tumor motion amplitude and frequency for when motion management should be used or not will therefore also vary from one modality to another.

The dose error is therefore related to the tumor motion amplitude by the time-integral relation of Eq. (2) above and is further filtered by the (nonisotropic) beamlet profile of Eq. (1). The modulation as an explicit function of time in Eq. (2) should be assumed to be important unless shown otherwise. We therefore are suggesting a focused update to the TG-76 report to include a criterion for the use of motion management techniques with dynamic IMRT that better includes the effects of frequency similarity and difference between MLC leaves and other modulation motions and tumor motion. Perhaps other issues with this criterion could be addressed as well such as for how long one should observe the intrafraction motion in order to parametrize it and if various parts of the tumor can all use the same criterion. One straightforward approach, potentially useful for the clinic, may be to suggest a motion delivery quality control and assurance check specific to each device (or type of device) and each patient's motion (or type of motion) to make sure interference effects such as those reported³ do not occur. We suggest that the treatment keep the machine's fundamental motion frequencies separate from the patient's fundamental tumor motion frequencies.

T. Rockwell Mackie has ownership interests in Tomotherapy, Inc., which is commercializing helical tomotherapy. This work was supported by United States National Institutes

of Health, National Cancer Institute Grant No. K25 CA119344.

^a)Electronic mail: mwkissick@wisc.edu

¹P. J. Keall, G. S. Mageras, J. M. Balter, R. S. Emery, K. M. Forster, S. B. Jiang, J. M. Kapatoes, D. A. Low, M. J. Murphy, B. R. Murray, C. R. Ramsey, M. B. Van Herk, S. S. Vedam, and J. W. Wong, "The management of respiratory motion in radiation oncology report of the AAPM Task Group 76," *Med. Phys.* **33**, 3874–3900 (2006).

²T. R. Mackie, T. Holmes, S. Swerdloff, P. Reckwerdt, J. O. Deasy, J. Yang, B. Paliwal, and T. Kinsella, "Tomotherapy: A new concept for the delivery of dynamic conformal radiotherapy," *Med. Phys.* **20**, 1709–1719 (1993).

³S. R. Chaudhari, S. M. Goddu, D. Rangaraj, O. L. Pechenaya, W. Lu, E. Kintzel, K. Malinowski, P. Parikh, J. D. Bradley, and D. A. Low, "Dosimetric variances anticipated from breathing-induced tumor motion during tomotherapy treatment delivery," *Phys. Med. Biol.* **54**, 2541–2555 (2009).

⁴M. W. Kissick, R. T. Flynn, D. C. Westerly, P. W. Hoban, X. Mo, E. T. Soisson, K. C. McCall, T. R. Mackie, and R. Jeraj, "On the impact of longitudinal breathing motion randomness for tomotherapy delivery," *Phys. Med. Biol.* **53**, 4855–4873 (2008).

⁵T. Bortfeld, K. Jokivarsi, M. Goitei, J. Kung, and S. B. Jiang, "Effects of intra-fraction motion on IMRT dose delivery: Statistical analysis and simulation," *Phys. Med. Biol.* **47**, 2203–2220 (2002).

⁶M. W. Kissick, S. A. Boswell, R. Jeraj, and T. R. Mackie, "Confirmation, refinement, and extension of a study in intrafraction motion interplay with sliding jaw motion," *Med. Phys.* **32**, 2346–2350 (2005).

⁷C. X. Yu, D. A. Jaffray, and J. W. Wong, "The effects of intra-fraction organ motion on the delivery of dynamic intensity modulation," *Phys. Med. Biol.* **43**, 91–104 (1998).

Michael W. Kissick^a)

*Department of Medical Physics, Wisconsin Institutes
for Medical Research, University of Wisconsin–Madison,
1111 Highland Avenue, Madison, Wisconsin 53705*

T. Rockwell Mackie

*Department of Medical Physics, Wisconsin Institutes
for Medical Research, University of Wisconsin–Madison,
1111 Highland Avenue, Madison, Wisconsin 53705
and Tomotherapy, Inc., 1240 Deming Way,
Madison, Wisconsin 53717*