EDITORIAL

# Imaging for high-precision thoracic radiotherapy

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The motion of intra-thoracic tumors and radiosensitive normal organs is an important consideration when planning curative radiotherapy. An individualized assessment of such motion is preferable over the use of standard 'planning margins', which may be based upon tumor location or patient characteristics (1-3). This is primarily because many tumors move less than 1 cm in any direction (3), thereby requiring smaller treatment fields. In addition, lung tumors may exhibit complex motions patterns, including hysteresis and be influenced by cardiac motion (4). Furthermore, patients with locally advanced lung cancer may exhibit motion in metastatic mediastinal nodes that exceeds that of the primary tumor or move maximally in a different phase (2,5). Identifying such variations in tumor motion can minimize the risk of compromising the effectiveness of radiotherapy delivery. Based on these studies, the European Organization for Research and Treatment of Cancer guidelines recommend use of respiration-correlated CT or 4-Dimensional CT (4DCT) scans for planning (6).

As 4DCT allows for the motion trajectory of a tumor to be imaged, it reduces the risk of introducing systematic errors into radiotherapy planning (7). Individualized 4DCT planning is particularly important for planning high-precision SABR in early-stage NSCLC (8). The widespread implementation of SABR in the Netherlands was accompanied by quality assurance programs for 4DCT imaging (9), and attention to such detail may have contributed to the remarkable survival improvements observed in the entire Netherlands population for Stage I lung cancer patients aged 75 years and older, who were diagnosed between 2001 and 2009 (10). The two-year survival in elderly Dutch patients undergoing radiotherapy improved from 35.8% to 52.5%, and median survival increased from 16.4 to 24.4 months.

Although multi-slice 4DCT scanners have been commercially available since 2003, this facility is not universally available and clinicians have had to explore alternative approaches. In this issue, Shen *et al.* describe an approach utilizing breath-hold CT scans at the ends of coached 'regular and quiet respiration' (11).

Although this approach captures more motion than a single conventional CT acquired at a random phase of respiration, some key drawbacks must be kept in mind. Firstly, patients who present for SABR are frequently unfit for surgery due to compromised pulmonary function (12). The ability of all such patients to perform a breath-hold procedure reproducibly is questionable. Furthermore, previous work has shown that audio-coaching can both increase the amplitude of tumor motion, as well as displace tumors (13). Therefore, the same audio-coaching must be performed during the delivery of SABR, where this may lead to longer treatment times.

No potential conflict of interest.

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An alternative low-technology approach for acquiring 4D information is slow CT scanning, which uses a slow gantry rotation to acquire images of tumor position taken at different points in the respiratory cycle (14). Dutch SABR recommendations suggest that if only 3DCT scans are available, the internal target volume for planning should be based either on multiple slow CT-scans covering the full tumour trajectory, or adding an additional 3-5 mm margin in all directions to the CTV determined on a single slow CT-scan (15). An alternative recommendation was to acquire a minimum of 3 conventional rapid planning scans over the entire tumor trajectory. FDG-PET scans have also been proposed for this purpose (16), although it is unclear if clinical outcomes using FDG-PET scans alone (without 4DCT) will produce acceptable local control rates. Additionally, the loss of contrast resolution has lead to uncertainties regarding the optimal use of FDG-PET for this purpose (17). Fluoroscopy in addition to a conventional CT scan has also been shown to be suboptimal for SABR (18).

Although some studies suggest that a single 4DCT scan acquired during quiet, uncoached respiration generates reproducible internal target volumes (18-20), artifacts on 4DCT have been reported in a significant proportion of such imaging studies (21). The latter highlights the need for careful review of images at the time of acquisition to ensure that the tumor region is free of artifacts.

After tumor motion has been defined, the planning target volume derived may be based on a motion-encompassing internal target volume that can be derived from the union of separate volumes in each phase of a 4DCT, or alternatively, from contouring on a maximum intensity projection of the 4DCT dataset (15,22). Dutch guidelines also accept use of an alternative to the internal target volumes concept, which is based on time-averaged mean positions of the tumor. Finally, changes in anatomy and breathing pattern between 4DCT and treatment, as well as between SABR fractions, can result in the internal target volume used for planning not being appropriate during treatment delivery (23). Therefore, even the use 4DCT to derive personalized margins to account for tumor motion alone may not be sufficient to ensure optimal cure rates. Daily image guidance strategies to visualize treatment targets are important during SABR to ensure that these individualized, reduced margins provide adequate coverage (24).

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