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Research Article

Assessment of Lung Tumour Motion and Volume Size Dependencies Using Various Evaluation Measures

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ABSTRACT

The purpose of the study was to assess internal target volume changes through the breathing cycle and associated tumour motion for lung patients and to establish possible correlations between different parameters. Respiration-induced volume changes with breathing cycle and the associated tumour motion were analyzed for 11 patients. Selected phases were the maximum and average intensity projections and the 10 phases of equal duration and separation obtained through the respiratory cycle. Tumour centre of mass (COM) motion planes were generated using least square fitting, and their angles and orientations were then compared between the cases studied. Trajectories that are composed by the points of COM location in different phases were identified, and their interrelation was assessed through different similarity measures. The results were used to determine if there is any correlation between parameters chosen and if the margins conventionally used for the planning target volume creation successfully encompassed lung tumour motion and volume change. The results show that the extent of tumour motion was related to its volume and location. The tumour displacement was predominantly left and inferior. Planar fitting to COM motion data through respiratory phases demonstrated some correlation in best fit motion plane positions between different data sets. In the plane fit comparison, for each patient, the lower root mean square error values showed that a good planar fit can be achieved for the COM motion path. The evaluation of the inhale and exhale trajectories may allow, for certain tumour locations and size, contouring on only inhalation or exhalation phases, knowing that tumour motion will be adequately covered on the other phases. Taking all the data into account and knowing the tumour size and location, a good estimate can be made of the motion plane position in the three-dimensional space and the required dosimetric margins.

RÉSUMÉ

L'étude cherchait à évaluer les variations du volume cible interne au cours du cycle respiratoire et le mouvement associé de la tumeur chez des patients atteints d'un cancer du poumon, en plus de chercher à établir des corrélations possibles entre différents paramètres. Les variations de volume causées par la respiration (dans le cadre du cycle respiratoire) et le déplacement associé de la tumeur ont été analysés chez onze patients. Le cycle respiratoire a été divisé en dix phases réparties équitablement sur le plan de la durée et de la séparation, et les images ont été reconstruites par projection d'intensité maximale et projection obtenue par moyennage. Les plans relatifs au déplacement du centre de gravité de la tumeur ont été obtenus par ajustement effectué au moyen de la méthode des moindres carrés; par la suite, leurs angles et leurs orientations ont été comparés entre les différents cas à l'étude. On a déterminé des trajectoires à partir des points représentant la position du centre de gravité évaluée lors de différentes phases du cycle respiratoire, puis la relation entre ces trajectoires a été évaluée au moyen de différentes mesures de similarité. Les résultats ont servi à établir l'existence possible d'une corrélation entre les paramètres choisis et si les marges normalement utilisées pour constituer le volume cible planifié suffisaient pour entourer complètement le déplacement et la variation du volume de la tumeur du poumon. Selon les résultats, l'importance du déplacement de la tumeur est liée à son volume et à sa position. Le déplacement des tumeurs s'effectuait surtout vers la gauche et vers le bas. Les plans d'ajustement aux données de déplacement du centre de masse au cours des phases du cycle respiratoire ont démontré une certaine corrélation entre les positions des plans les mieux ajustés de différentes séries de données. Dans le cadre de la comparaison des plans d'ajustement, les faibles valeurs de l'erreur quadratique moyenne ont prouvé la possibilité d'obtenir un bon plan d'ajustement pour la trajectoire de déplacement du centre de gravité, et ce, pour chaque patient. En ce qui concerne certaines combinaisons de taille et d'emplacement de tumeur, l'évaluation des trajectoires établies

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pour les phases d'inspiration et d'expiration pourrait permettre de recourir au contourage uniquement durant les phases d'inspiration ou des phases d'expiration, car le déplacement de la tumeur serait adéquatement entouré lors des autres phases. En tenant compte de l'ensemble des données et en connaissant la taille et l'emplacement de la tumeur, il est possible d'obtenir une bonne estimation de la position du plan relatif au déplacement dans un espace en 3D et des marges de sécurité requises.

Keywords: 4D CT; singular value decomposition; least square fit; similarity measures; centre of mass

Introduction

Commercial treatment planning systems that are currently available are capable of calculating dose distributions based on static three-dimensional (3D) computed tomography (CT) images [1,2], where the tumour and surrounding healthy tissues are not moving during the dose delivery. However, respiratory-induced organ motion can result in considerable movement of the lesion during the breathing cycle, leading to discrepancies between the dose delivered and the dose planned [3–7]. In the case of lung tumours, anatomic motion should be accounted for during treatment planning. There are a number of methods used to achieve this, including breath hold, respiratory gating, and coached breathing. Some studies suggested models that would incorporate the effect of the respiratory-induced organ motion on the dose distribution [8], and some have proposed four-dimensional (4D) dose calculation methods [1,3,9–12].

In this work, we are evaluating internal margin as a part of the dosimetric margin [13,14]. The internal margin is defined to take into account variations in the size, shape, and position of the tumour volume in relation to anatomic reference points.

Because dose escalation may be associated with a higher cure rate for certain localized cancers [15], it is imperative that we explore ways to reduce the overall tumour margins while ensuring that the full extent of the tumour volume is treated. Loss of accuracy in patient setup may have serious consequences on the expected tumour control probability and surrounding normal tissue complications. This is especially a concern in thoracic (lung) tumours because of the respiratory-induced intrafraction motion [16].

Tumours in the thorax can move up to 3–5 cm [17,18]. This motion can be accounted for by various methods. Such methods include measuring and treating the entire track of tumour travel using 4D CT for targeting, applying abdominal compression to reduce motion, gating the treatment to a specific portion of the respiratory cycle, active breathing control, or tracking the tumour with the radiation beam [19].

The generation of a single 4D CT scan is a simple procedure that poses no problems, even for patients with compromised respiratory function. A 4D CT scan involves a digital reconstruction of the CT slices over the respiratory cycle, yielding a 4D data set. Published data [20] have shown that individualized assessment of tumour mobility can improve the accuracy of target definition, and this is best achieved by using a 4D CT.

For advanced conformal radiotherapy, several approaches have been proposed to take respiration movements into account [21]. These approaches allow for the reduction of the internal margin and more accurate treatment delivery. It has been reported that if respiratory management techniques are not included when treating lung tumours with volumetric modulated arc therapy, the tumour may be underdosed [22]. It has also been shown that respiration-induced tumour motion in the lung is relatively modest, and typically does not exceed 1.0 cm [18], except for lesions that are located in the lower half of the lung near the diaphragm [23–25].

The focus of this article is the evaluation of the internal target volume changes through the breathing cycle and associated tumour motion for lung patients. The methods used allow us to visualize target motion and volume change based on size and/or location. Various ways of describing tumour location in the 3D space are discussed, and correlations are established between the different factors that may be influencing motion extent.

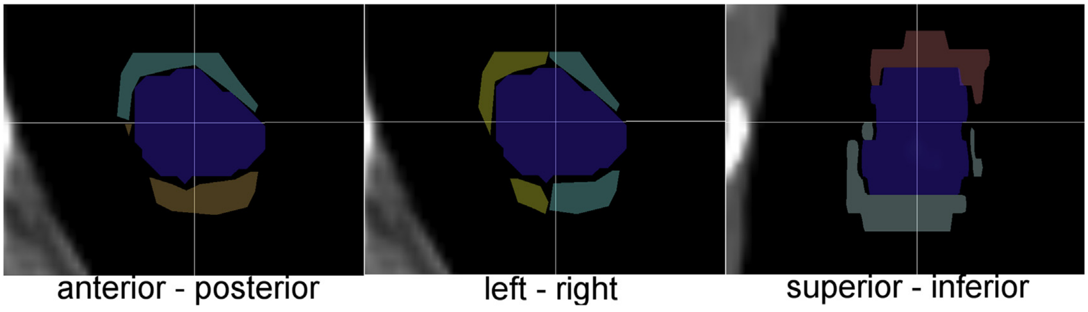

Figure 1. Tumour volume sum from all the phases–average intensity projection tumour volume (division into halves).