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The Quantification of Intra-Fractional Tumour Motion Errors in Lung Stereotactic Ablative Radiotherapy Patients

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Abstract

This work aims at quantifying intra-fractional motion errors and evaluating the appropriateness of a Planning Target Volume (PTV) margin for Queen Elizabeth (QE) Hospital's patients. Intra-fractional motion errors were quantified for 29 patients who underwent lung Stereotactic Ablative Radiotherapy (SABR) treatment at the cancer centre of QE Hospital. One hundred thirty post-Cone Beam Computed Tomography (CBCT) scans were collected to calculate these errors. In terms of the adequacy of a PTV margin, the intra-fractional motion errors that were calculated are combined with other geometric errors which were taken from historical audit studies. Then, the combined outcome was compared with the common PTV margin that is delineated by most United Kingdom (UK) oncology centres. The findings of this study showed that the systematic component of intra-fractional motion error is equal to 0.08, 0.08 and 0.08 cm in right/left, superior/anterior and anterior/posterior directions, respectively, While the random component of this error is equal to 0.11, 0.13 and 0.14 cm. In addition to that, a PTV margin of 0.5 cm is the appropriate margin for QE Hospital's patients and this volume is compatible with the common PTV margin that is delineated by the most UK oncology centres. This work concluded that A PTV margin of 0.5 cm is the suitable volume for lung SABR patients at QE Hospital.

Keywords

SABR, Geometric Errors, Lung Cancer

1. Introduction

In recent years, rapid evolvement of radiotherapy techniques, for example intensity modulated radiotherapy (IMRT) and SABR treatments, has enabled radiation oncologists to escalate tumour dose without damaging normal tissues to improve therapeutic index [1]. However, issues, such as geometric errors, still hamper these developed technologies. These errors can affect the precision of these technologies in delivering a prescribed dose to the target [2]. Tumour volume delineation, setup error and motion error are the common geometric errors [3]. Intra-fractional motion error is very common in lung SABR treatment because of respiratory motion that has a blurring effect on tumour dose [1] [4]. Unfortunately, most intra-fractional motion error studies were focused on the head and neck. As a result of that, this study will investigate this kind of error in lung SABR patients by using CBCT in order to quantify intra-fractional motion error and evaluate the required PTV margin for them.

Daily tumour motion in lung SABR treatment is the main challenge for radiographers. This variation in tumour position will lead to inaccurate dose delivery to the target and escalate the dose to surrounding normal tissues [5]. As a result of that, scholars thought to consider this uncertainty with other geometric errors in the PTV delineation process [5]. Recently, this error has been managed by CBCT. This kind of Image-Guided Radiotherapy (IGRT) can assist radiographers to quantify and detect daily intra-fractional motion errors [6]. PTV margin differs from one centre to another, and this variation is due to the estimation of geometric errors for a cohort of patients. According to the survey of Distefano and his colleagues, a 0.5 cm PTV volume was the common volume among UK centres [7]. This volume will be used in this study as a gold standard to evaluate PTV margin. The work described in this study uses data from the SABR database of QE Hospital, which provides daily intra-fractional motion errors for each patient with anatomical images.

This data will be used in the quantification of systematic and random components of intra-fractional error. Values of other geometric errors were taken from historical reports that were done by QE Hospital staff.

2. Material and Methods

This retrospective study includes 29 patients (18 males, 11 females) with early stage non-small cell carcinoma (26 patients T1 stage, 3 patients T2 stage). They received SABR lung treatment in the period between January 2013 and December 2014. Patients were treated with a range of different fractionation regimes (20 patients 55 Gy/5 Fractions, 9 patients 54 Gy/3 Fractions). Additionally, SABR was given to all patients on immobilisation devices (18 patients black mattress, 11 patients Vag bag and black mattress). Patients' tumours were approximately spherical and less than 5 cm in diameter, and 41.4% of these tumours located on the right upper lobe of the lung. The mean standard Deviation (SD) of age of patients was 75.4 ± 8.72 years (Range: 50 - 92 years).

Measurement of intra-fractional motion error was performed as follows; firstly, 130 post-CBCT scan shifts were collected. Then, the individual motion error was estimated for each patient. After that, overall population error was calculated by taking the mean of all individual mean errors. Next, all the outcomes of these calculations gave the systematic component of this error. To calculate the random component of this error, the standard deviation of motion errors around the mean was quantified. Then, the results gave the random component of the intra-fractional error.

To evaluate PTV margin in this study, the calculated systematic and random components of each geometric error in this study were applied to the Van Herk formula that gives the appropriate PTV margin. After that, the resulted PTV was compared against the common volume of the PTV margin in UK radiation oncology centres *i.e.* 0.5 cm PTV margin [7].

3. Statistical Analysis

The mean and standard deviation of post CBCT scans are calculated with Excel software. Systematic and random components motion errors were also quantified by Excel software.

4. Results

4.1. Measured Errors

The calculation of intra-fractional errors was mainly based on post-scan shifts. The average SD of mean tumour shifts from intra-fraction CBCT to planned CBCT were 0 (±0.1) cm, 0 (±0.1) cm and 0 (±0.1) cm in the R/L (Right/Left), S/I (Superior/Inferior) and A/P (Anterior/Posterior) directions, respectively. Systematic and random components of these errors were calculated with Van Herk equations and it was found that systematic components were equal to 0.08 cm, 0.08 cm and 0.08 cm in the R/L, S/I and A/P directions, respectively, while random components of this error were equal to 0.11 cm, 0.13 cm and 0.14 cm.

4.2. Other Relevant Uncertainties and Overall Required PTV Volume

In order to quantify the appropriate PTV margin for the cohort of patients, all geometric errors should be quantified for two general components, systematic and random components. In terms of intra-fractional motion error, both systematic and random components were calculated in this study. Inter-fractional setup errors, matching errors and mechanical errors were other geometric errors that should be considered in the quantification of the PTV margin. The systematic and random components of these errors were taken from the historical audit studies that were performed by radiation oncology staff of QE Hospital (Table 1). However, the systematic and random components of inter-observer delineation error were very difficult to obtain, since agreement among radiologists and oncologists is rarely reported. Since tumours are approximately spherical in shape, the rotation of the tumour itself between or during treatment does not need to be explicitly accounted for, but is incorporated in the measured translational tumour shifts.

The combined systematic and random components of all previous errors were

Table 1. Systematic and random components for error types and total PTV margin.

Parameters	Systematic (cm)			Random (cm)		
Direction	L/R	S/I	A/P	L/R	S/I	A/P
Inter-# setup	0.04	0.04	0.07	0.08	0.07	0.08
Intra-# motion	0.08	0.08	0.08	0.11	0.13	0.14
Matching	**0.02**	**0.03**	**0.02**	**0.06**	**0.07**	**0.07**
Mechanical	0.06	0.15	0.08	0.01	0.025	0.025
Combined Σ^2	0.01	0.03	0.01	0.02	0.02	0.03
Σ/σ	0.11	0.17	0.13	0.15	0.17	0.18
PTV Margin	0.35	0.51	0.41			

quantified. It is found that the combined systematic components of errors were 0.01 cm, 0.03 cm and 0.01 cm in the R/L, S/I and A/P directions, while the combined random components were 0.02 cm, 0.02 cm and 0.03 cm as shown above (Table 1).

The above data generates the appropriate PTV margin for this group of patients. This margin was quantified by using the Van Herk formula. It is noticed that the total margins accounting for all previous errors except rotational and inter-observer delineation errors were 0.35 cm, 0.51 cm and 0.41 cm in the L/R, S/I and A/P directions, respectively (See table 4.1). This outcome indicates that a PTV margin of 0.5 cm in all directions is appropriate and this volume is compatible with the common volume of PTV that is delineated by the most UK radiation oncology centres [7].

4.3. Discussion

It is worth mentioning that prior to this study, few known studies were available that quantify intra-fractional motion errors for lung SABR treatment. In this work, these errors were calculated in all orthogonal directions. These findings were compatible with some studies' findings [8], and disagreed with others [9]. The reason behind this controversy was that some of these studies used different motion management techniques in their methods, which might cause different amounts of intra-fractional motion errors that differ with the findings of this study. CBCT was used as tool to quantify and detect intra-fractional motion errors. The intra-fractional motion errors that were observed in this study were similar to the study by Snoke and colleagues [10].

Their study indicated that the systematic intra-fractional motion error component was 0.08, 0.08 and 0.09 cm in anterior/posterior, left/right and superior/inferior directions and the random component was 0.11, 0.11 and 0.14 cm in the same orthogonal directions. However, the study by Ruijiang *et al.* [9] focused on intra-fraction lung tumour motion error using CBCT. It observed that the mean tumour shifts from intra-fraction CBCT to planned CBCT were 0.16, 0.1 and 0.15 cm in anterior/posterior, left/right and superior/inferior directions. These values are higher than the mean of tumour shifts in this study. This difference may be due to the impact of different motion management methods, such as breath-holding technique and respiratory gating.

An appropriate PTV is the important part in improving local tumour control and saving normal tissues from excessive radiation doses [10]. Some centres reduce this volume so it is narrower [7] which might cause failure in local tumour control [10]. Others extend this volume so it is wider [7] and cover the whole target, and this might contribute to increase the dose to surrounding normal tissues [10]. However, most UK centres apply a 0.5 cm PTV volume to include all geometric errors and to ensure tumour coverage [7]. Based on the findings of this study, the appropriate PTV that accounts for all errors except rotational and delineation errors was 0.35 cm, 0.51 cm and 0.41 cm in the R/L, S/I and A/P directions, respectively. This outcome indicates that a PTV of 0.5 cm in all directions is appropriate at QE hospital. This volume was similar to the volume that was quantified in most UK radiotherapy centres [7]. Similarly, the study by Takahashi and colleagues, which applies 4D-CBCT in treatment to quantify and detect intra-fractional motion errors, concluded that a 0.5 cm PTV volume is adequate for its sample of patients [11] and emphasises that this volume is enough to include all geometric errors[11].

5. Conclusion

It was noticed that the appropriate PTV margin at QE Hospital was 0.5 cm, which accounts for all geometric errors in lung SABR treatment. This volume was compatible with the PTV margin that is delineated by most common UK oncology centres.

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