Establishing tumour tracking accuracy in free-breathing respiratory gated SBRT of lung cancer

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Abstract. Free-breathing respiratory gated SBRT of surgically inoperable lung cancer has been clinically commissioned. This study was to establish the tumour tracking accuracy under clinical conditions based on an implanted fiducial marker. A Visicoil™ marker embedded in tissue-equivalent material mounted in a phantom (ET Gating Phantom™ Brainlab) driven by a patient's breathing data was treated with the ExacTrac™ system. This one-dimensional moving marker represented a tumour motion in superior-inferior (S-I) direction measured through 4DCT study of the same patient. Both Gafchromic™ films and the stereoscopic kV images were used for tracking the position of the marker. For tumour motion at magnitudes of 10, 20 and 29 mm and treated with corresponding gate widths of 50%, 33% and 20% of free breathing amplitude, the implanted marker was able to be tracked with a deviation ≤1.53 mm to its planned position.

1.Introduction:

The goal of respiratory gated radiation therapy is to reduce the volume of healthy tissue irradiated while maintaining full coverage of a moving planned target volume (PTV). Hence, it is important to accurately measure and track tumours at sites in the thorax and abdomen affected by respiratory motion during radiotherapy planning and treatment with external beam [1]. Tenn *et al.* investigated the targeting accuracy of an image-guided gating technique for stereotactic body radiotherapy (SBRT) using phantoms [2]. However, that study simplified the clinical situation somewhat because it used a sinusoidal pattern to represent the patient's breathing trace. Clinically an actual breathing trace is not sinusoidal but complex, irregular and varied in both amplitude and period. This study examines the tracking accuracy based on a fiducial marker implanted in the gross tumour volume for respiratory

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gated delivery to a lung tumour in a commercial breathing phantom driven by the superior-inferior component of an actual patient's breathing trace.

2. Method:

A Visicoil™ 0.75 mm diameter gold coil marker was embedded in a Perspex plate that was mounted on ET Gating Phantom™ (Brainlab AG Germany) and moved along the superior-inferior (S-I) direction of the patient to simulate the predominant respiratory motion of a lung tumour (figure 1). A Gafchromic™ RT QA film was placed underneath the marker to record its position when a beam was delivered. To enhance the marker projection on the film, a ball bearing was added between the marker and the film.

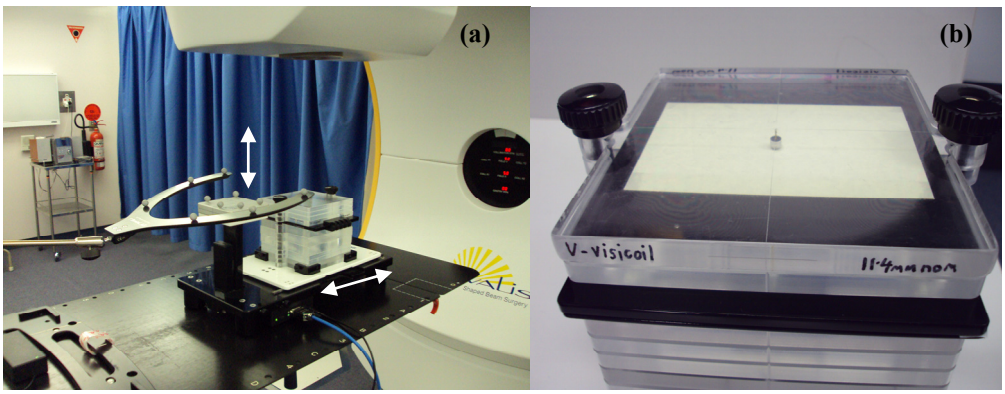

Figure 1. The setup of phantom and fiducial marker: (**a**) The block was moving in the S-I direction while the skin markers were moving up-and-down and the reference remained still; (**b**) A Visicoil™ embedded in a Perspex plate above a ball bearing and film placed in a cassette (black).

The horizontal motion of the phantom was obtained from the corresponding component of the lung tumour motion while the vertical motion was measured from the same patient's external chest. The magnitudes of both motion ranges were scaled to reflect the possible clinical measurements. The phantom was irradiated on a Novalis™ Classic linac equipped with ExacTrac™ (Brainlab AG Germany) robotic couch and in-room stereoscopic kV imager. During the setup and delivery

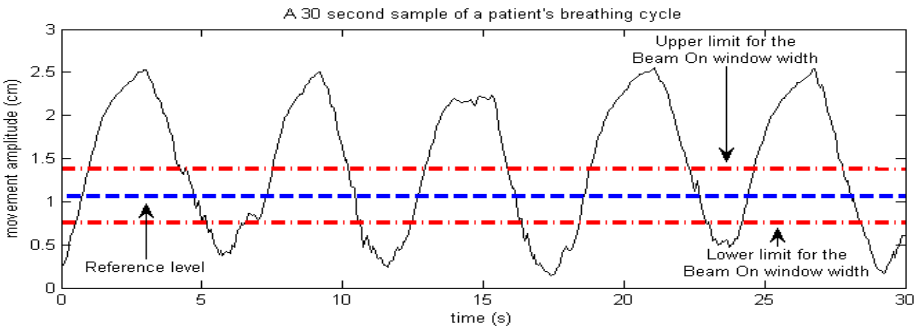

Figure 2. A 30-second sample of a patient's representative breathing trace. The beam-on gate was used in the region between the dash-dot lines. Beam-on gate widths of 50%, 33% and 20% of the average full breath window were utilised, centred on a reference level (dashed line).

processes, the gold marker was moving within the vicinity of the beam isocentre and its position was verified via X-ray images acquired by the ExacTrac™ kV imager. To enable the verification images to be acquired at the beginning and end of the beam-on gate, the gate was placed at the end of exhale but did not include the trough of this breathing trace. The displacement of the marker from the isocentre could be displayed and was used to define the MV beam-on gate width as illustrated in figure 2. In this study, the marker was set at isocentre at reference level of 33% of magnitude above the trough. The MV beam-on gate widths of 50%, 33% and 20% of full amplitude were used to satisfy the clinical requirements when treating a tumour with a relatively small, medium or large motion range respectively.

A 6MV MLC shaped beam from a clinical plan was delivered at gantry angle zero to the Visicoil™ marker positioned at isocentre in the phantom. Both non-gated motionless treatment and gated treatments at three motion ranges of 10, 20 and 29 mm were delivered sequentially. A dose of 200 MU at 800 MU/min. was delivered in each treatment. The spatial positions of the marker were recorded on films located immediately beneath. Figure 3 shows the motionless and gated films and the vertical dose profiles over the marker at the field centre.

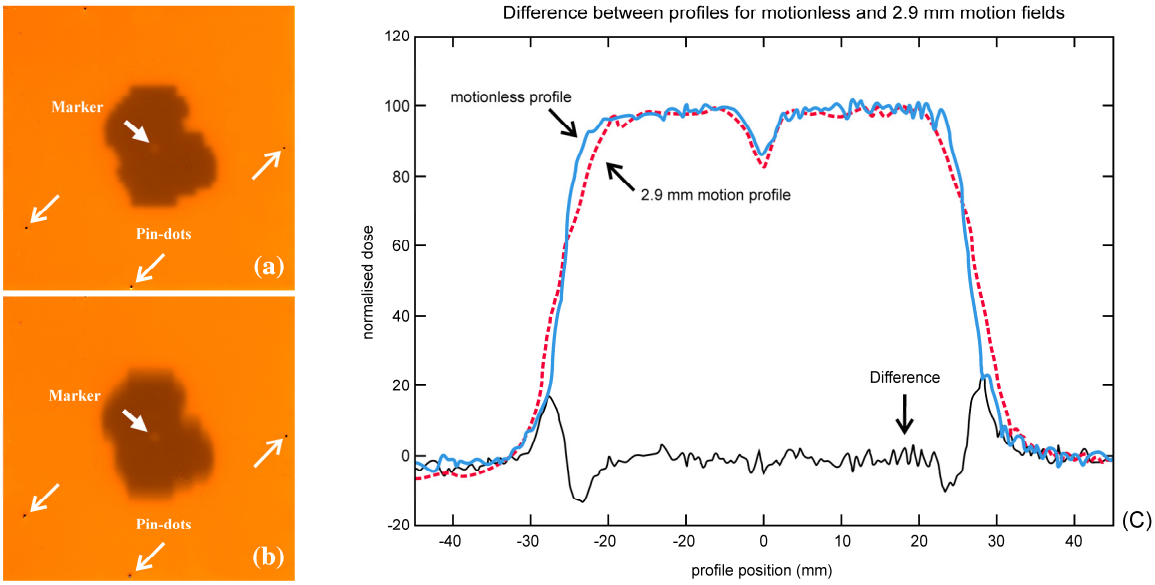

Figure 3. Visicoil™ marker projections in: (**a**) Motionless film; (**b**) Film of motion range of 29 mm and gate width of 33% of full amplitude; (**c**) Plot of vertical profiles showing displacement between motionless marker/isocentre (thick) and averaged position (dotted) in the gated field.

By using the technique described by Tenn *et al.*[2], films from both the motionless and the motion-gated deliveries were scanned and co-registered with pin-dots (shown in figure 3(**a**) and 3(**b**)) before a vertical profile of relative dose along the film motion direction was generated over the marker (ball bearing) projection. In the centre of these profiles, the separation in millimetres between local minimums was the displacement between marker positions on the gated and the motionless films, as displayed in figure 3(**c**).

3. Results:

The measured displacements of fiducial marker projections on films between gated fields and motionless field where the marker was at machine isocentre for three tumour motion ranges of 10 mm, 20 mm and 29 mm, at three gate widths of 20%, 33% and 50% of the full respiration amplitude are displayed in Table 1. The beam was only delivered in exhalation phase. Since the film was placed in a cassette below the marker and the ball bearing, a correction factor to scale the films to the isocentre level has been applied to the result.

Table 1. Measured displacements of Visicoil^{TM} to isocentre in S-I direction only for gated deliveries using 1D component of patient breathing trace.

Gate width in percentage of full respiration amplitude	Marker/tumour motion magnitude (mm)		
	10 mm	20 mm	29 mm
20%	1.53	1.53	0.0
33%	1.02	1.53	0.51
50%	0.0	0.51	1.02

4. Discussions:

The results in Table 1 above are mainly due to random distribution in multiples of 0.51 mm as the bin size in vertical profiles is 0.51 mm. The maximum deviation from the ideal tumour tracking is 1.53 mm, which is larger than the uncertainty of 0.51 mm arising from binning. Due to the limitation in this study that the phantom can move in one dimension, the fiducial marker (tumour) motion was examined along the superior/inferior direction only. With the same system a 3D accuracy of 1.7 mm was reported by Willoughby *et al.* from a phantom study [3]. Seppenwoolde *et al*. reported that thoracic tumour motion was greatest along the superior-inferior direction [4], hence the obtained result should reflect the maximal tracking uncertainty. However, these results indicate only a threshold of accuracies measured from a single clinical case and the breathing data will vary for each patient. Further study is therefore needed using the tumour motion data of more patients and more sites as well as taking into account the tumour hysteresis effect. A sub-millimetre systematic accuracy for stereotactic radiosurgery of cranial tumour using the same equipment has been reported by Ackerly *et al*. [5]. By following this method, the localisation accuracy in SBRT of tumours affected by respiration can be established. This accuracy is in line with that previously reported and is useful when considering margins for clinical treatment.

5. Conclusions:

With the method used in this clinical simulation study, the implanted fiducial marker in phantom can be tracked in the S-I direction with a deviation of equal to or less than 1.53 mm from its planned position during free-breathing respiratory gated deliveries of 20%, 33% or 50% of full expiration amplitude generated from skin surface surrogate of a real clinical case, for tumour moving in the range up to 29 mm.

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