Validation of ^{3}He-MRI to CT image registration and the impact on NSCLC IMRT planning

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Introduction

For patients with non-small cell lung cancer (NSCLC) who undergo radiotherapy treatment, functional pulmonary reserve may be severely reduced as radical radiotherapy will cause damage to non-cancerous lung tissue in addition to the intended target volume. The key to reducing the dose to healthy tissue may be to use supplementary images of lung ventilation and perfusion to assist in the planning of radiation fields. One possible approach could be to register images of the distribution of hyperpolarized helium-3 MRI (^{3}He-MRI) to treatment planning CT [1]. The functional data could then be applied as an additional constraint in the inverse planning procedure for intensity modulated radiotherapy (IMRT). To investigate this concept, the aims of this study were to assess two important aspects of the proposed methodology: firstly to quantify the accuracy of the image registration of ^{3}He-MRI to treatment planning CT, and secondly to evaluate the impact of registered ^{3}He-MRI on IMRT planning.

Methods

Six patients with NSCLC underwent ^{3}He ventilation MRI [1,2] which was fused with radiotherapy planning CT using rigid registration. ^{3}He was polarized to 30% by optical pumping with rubidium spin exchange apparatus (GE Healthcare & Spectra Gases). During breath-hold of a 300ml ^{3}He/700ml N_2 mixture, 19 coronal *in vivo* images (Fig. 1) were acquired with a 1.5T whole body system (Philips Medical Systems Eclipse) with a flexible twin saddle quadrature T-R coil (IGC Medical Advances). Using in-house custom Matlab (MathWorks Inc) software, registration accuracy was assessed using an overlap coefficient (Ω), which is calculated as the proportion of the segmented ^{3}He-MR slice volume (V_{MRI}) that intersects the segmented CT lung slice volume (V_{CT}) expressed as a percentage of V_{MRI}, $\Omega = 100\times(V_{MRI} \cap V_{CT})/V_{MRI}$, where the higher the overlap value the better the registration. Segmentation was performed manually by an experienced lung radiotherapy consultant with a suitable windowing of the ^{3}He-MR images that varied from patient to patient due to differences in the signal-to-noise-ratio. The registered ^{3}He-MRI was segmented in Philips Medical Systems ACQSIM and the contours exported to the Eclipse planning system (Varian Medical Systems) for IMRT planning (Fig. 2). Functional lung tissue was defined as the intersection of the lung CT volume with well-ventilated lung segmented from the registered ^{3}He images ($V_{MRI} \cap V_{CT}$). Total lung volume included the ipsalateral and contralateral lung but excluded the gross tumor volume (GTV). For each patient, IMRT plans constrained with and without regions of well-ventilated lung defined by the registered ^{3}He-MRI were compared by evaluating the volume of lung receiving a dose ≥ 20Gy (V_{20}).

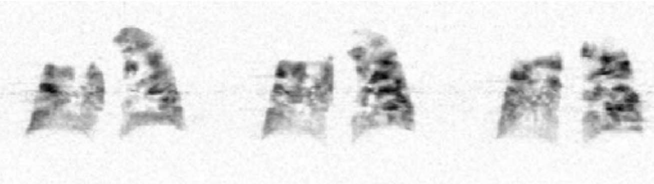

Fig. 1 Example coronal ^{3}He-MRI for a NSCLC patient.

Results

Table 1 provides the mean and standard deviation of Ω for each patient. Based on all the registered images containing CT defined lung, for patient 4 (Ω=97.0±1.9) and patient 5 (Ω=96.7±2.2) the registration is highly accurate and has low variance. Patients 1, 2 and 6 show good accuracy (Ω=85.5±15.1, Ω=89.6±5.8 and Ω=88.2±8.1), while patient 3 exhibits the lowest accuracy and high variability (and Ω=71.9±14.6). Similar values are found when Ω is calculated over the registered images containing the PTV or GTV, except for patient 3 which is 9.8% less accurate over the GTV images. Overall, the ^{3}He-MRI and CT were registered with sufficient accuracy to enable functionally guided IMRT planning (median overlap 89%, range 72–97%). Table 2 displays a summary of the IMRT planning results. In comparison with the total lung IMRT plans, IMRT constrained with ^{3}He-MRI reduced the V_{20} not only for the well-ventilated lung (median reduction 3.1%, range 0.4–5.1%, p=0.028) but also for the total lung volume (median reduction 1.6%, range 0.2–3.7%, p=0.028).

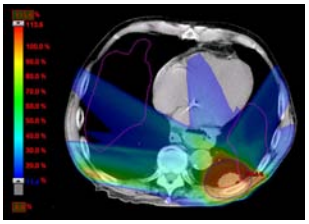

Fig. 2 Example IMRT plan.

Patient	Within lung images	Within PTV images	Within GTV images
1	85.5 (15.1)	82.8 (16.3)	85.8 (12.2)
2	89.6 (5.8)	89.2 (6.4)	86.4 (4.7)
3	71.9 (14.6)	66.3 (14.7)	62.1 (13.0)
4	97.0 (1.9)	97.7 (1.3)	98.1 (1.0)
5	96.7 (2.2)	96.6 (2.6)	97.0 (2.7)
6	88.2 (8.1)	90.0 (5.8)	89.5 (4.2)

Table 1) Mean (standard deviation) of the overlap coefficient (%) calculated for all slices containing a) CT defined lung, b) the planning target volume (PTV), and c) the gross tumour volume (GTV).

Patient	FLV$_{20}$ (%)		TLV$_{20}$ (%)	
	Plan A	Plan B	Plan A	Plan B
1	32.8	32.4	31.4	31.2
2	19.4	18.8	23.2	22.8
3	28.1	24.3	27.6	23.9
4	27.1	23.5	27.1	24.7
5	7.6	5.0	11.7	9.0
6	33.9	28.8	19.0	18.3
Median	27.6	23.9	25.2	23.4
Wilcoxon	p = 0.028		p = 0.028	

Table 2) Plan A: Without ^{3}He-MRI. Plan B: With ^{3}He-MRI.
FLV$_{20}$: % functional lung receiving ≥ 20 Gy.
TLV$_{20}$: % total lung receiving ≥ 20 Gy.

Conclusions

Statistically significant improvements to IMRT plans are possible using functional information provided by ^{3}He-MRI that has been registered to radiotherapy planning CT. Registration errors are likely to be due to differences in MRI (arms down, breath-hold) and CT (arms up, free-breathing) patient setup and breathing protocols. It remains the subject of future research to minimize and quantify the impact of such differences.

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References

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