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Original Article

Superiority of Deformable Image Co-registration in the Integration of Diagnostic Positron Emission Tomography-Computed Tomography to the Radiotherapy Treatment Planning Pathway for Oesophageal Carcinoma

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Abstract

Aims: To investigate the use of image co-registration in incorporating diagnostic positron emission tomography-computed tomography (PET-CT) directly into the radiotherapy treatment planning pathway, and to describe the pattern of local recurrence relative to the PET-avid volume.
Materials and methods: Fourteen patients were retrospectively identified, six of whom had local recurrence. The accuracy of deformable image registration (DIR) and rigid registration of the diagnostic PET-CT and recurrence CT, to the planning CT, were quantitatively assessed by comparing co-registration of oesophagus, trachea and aorta contours. DIR was used to examine the correlation between PET-avid volumes, dosimetry and site of recurrence.
Results: Positional metrics including the dice similarity coefficient (DSC) and conformity index (CI), showed DIR to be superior to rigid registration in the co-registration of diagnostic and recurrence imaging to the planning CT. For diagnostic PET-CT, DIR was superior to rigid registration in the transfer of oesophagus (DSC = 0.75 versus 0.65, $P < 0.009$ and CI = 0.59 versus 0.48, $P < 0.003$), trachea (DSC = 0.88 versus 0.65, $P < 0.004$ and CI = 0.78 versus 0.51, $P < 0.0001$) and aorta structures (DSC = 0.93 versus 0.86, $P < 0.006$ and CI = 0.86 versus 0.76, $P < 0.006$). For recurrence imaging, DIR was superior to rigid registration in the transfer of trachea (DSC = 0.91 versus 0.66, $P < 0.03$ and CI = 0.83 versus 0.51, $P < 0.02$) and oesophagus structures (DSC = 0.74 versus 0.51, $P < 0.004$ and CI = 0.61 versus 0.37, $P < 0.006$) with a non-significant trend for the aorta (DSC = 0.91 versus 0.75, $P < 0.08$ and CI = 0.83 versus 0.63, $P < 0.06$) structure. A mean inclusivity index of 0.93 (range 0.79–1) showed that the relapse volume was within the planning target volume ($PTV_{PET\text{-}CT}$); all relapses occurred within the high dose region.
Conclusion: DIR is superior to rigid registration in the co-registration of PET-CT and recurrence CT to the planning CT, and can be considered in the direct integration of PET-CT to the treatment planning process. Local recurrences occur within the $PTV_{PET\text{-}CT}$, suggesting that this is a suitable target for dose-escalation strategies.

Key words: Deformable image registration; oesophageal cancer; pattern of local recurrence; PET-CT imaging

Introduction

Currently in the UK, oesophageal cancer has a high mortality rate, with an estimated 5 year survival rate of

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15% [1]. Many patients with locally advanced oesophageal cancer are treated with chemoradiation. A large percentage of these patients will experience local recurrence within the first 2 years after treatment [2,3]. Some studies suggest that persistent disease may be a result of inaccurate gross tumour volume (GTV) delineation [4]. Consequently, accurate detection and delineation of the extent of disease is important. Improving this definition of the GTV remains a challenge in oesophageal cancer [5,6].

The role of fluoride-18 fluorodeoxyglucose (FDG) positron emission tomography-computed tomography (PET-CT) imaging has been explored in recent years, with applications including tumour staging, target delineation and assessment of tumour response to treatment [7,8]. PET-CT can assist in identifying the metabolically active tumour, but there remains uncertainty in how this information should be used [9–12]. Some studies suggest that PET-CT may enable more accurate tumour delineation, compared with CT alone [6,9,13]. There are many difficulties in integrating PET-CT to the treatment planning process; primarily because the staging PET-CT is typically acquired before a decision to proceed with non-surgical treatment. Consequently these scans are not acquired in a radiotherapy treatment position. An additional PET-CT scan in the treatment position could be acquired, but is resource intensive, onerous for patients and results in an increased radiation dose. Alternatively, the diagnostic PET-CT could be incorporated into the planning pathway using image co-registration, but the accuracy of this co-registration process is essential. Rigid co-registration in a region of interest may be suboptimal due to positional differences between the PET-CT and planning CT. Deformable image registration (DIR) provides an alternative option, which has been used in other tumour sites [14]. It has many applications in radiotherapy treatment planning, including calculating accumulative dose over a radiotherapy treatment course and auto-segmentation for target/organ at risk delineation/to account for contour changes in adaptive radiotherapy [15–22].

Analysis of the pattern of local recurrence is critical in evaluating the quality of the radiotherapy treatment. DIR has been used for this purpose in head and neck cancer [23–25]. It represents a promising method to evaluate local recurrence and to determine whether these recurrences are within the original treatment planning volume. DIR can be used to examine the pattern of recurrence relative to the metabolically active PET-CT volume, to determine whether this represents a potential target for dose-escalation strategies.

Assessment of the accuracy of image co-registration is essential to allow the incorporation of diagnostic PET-CT to the radiotherapy planning process and to validate accurate recurrence analysis. The aim of this study was to quantify the accuracy of co-registration of diagnostic PET-CT and relapse imaging to the planning CT, using both DIR and rigid registration, and to correlate the site of local recurrence with pre-treatment PET avidity.

Materials and Methods

Patients

This retrospective study was carried out using datasets from consecutive patients treated under the care of a single radiation oncologist between 2009 and 2010. Eligible patients fulfilled all of the following criteria: (i) squamous cell or adenocarcinoma of the oesophagus, (ii) treated with concurrent chemoradiotherapy with curative intent, (iii) baseline FDG-PET-CT, (iv) availability of all diagnostic imaging, planning CT and, where relevant, relapse imaging. Sixteen patients were identified, of whom two were excluded as all datasets could not be obtained. Six of the 14 patients included subsequently experienced a local relapse. A summary of the patient characteristics is included in Table 1.

Diagnostic PET-CT scans were acquired an average of 1.4 months before the planning CT scan (range 0.1–4.5 months). Relapse CT scans were acquired an average of 11 months after the planning CT scan (range 4–16.5 months).

Imaging

As part of routine clinical staging, all patients underwent an FDG-PET-CT scan (Discovery ST, GE Medical Systems, Milwaukee, WI, USA). Patients were scanned on a curved couch-top with arms raised. Images were acquired from skull base to upper thigh, 60 min after a 400 MBq dose of intravenous fluorine-18 FDG. The CT component of the PET-CT was carried out according to a standardised protocol with the following settings: 140 kV; 80 mAs; tube rotation time 0.5 s per rotation; pitch 6; section thickness 3.75 mm

Table 1
Patient characteristics

Patient details (n=14)	
Gender (n)	
Male	7
Female	7
Age (years)	
Average	67
Range	50–83
Histology (n)	
Adenocarcinoma	4
Squamous cell carcinoma	10
Clinical staging (n)	
T2N0M0	4
T2N1M0	1
T3N0M0	3
T3N1M0	5
T4N1M0	1
Location (n)	
Upper	2
Lower	6
Mid	6