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Original Article

Validation of a Magnetic Resonance Imaging-based Auto-contouring Software Tool for Gross Tumour Delineation in Head and Neck Cancer Radiotherapy Planning

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Abstract

Aims: To carry out statistical validation of a newly developed magnetic resonance imaging (MRI) auto-contouring software tool for gross tumour volume (GTV) delineation in head and neck tumours to assist in radiotherapy planning.

Materials and methods: Axial MRI baseline scans were obtained for 10 oropharyngeal and laryngeal cancer patients. GTV was present on 102 axial slices and auto-contoured using the modified fuzzy c-means clustering integrated with the level set method (FCLSM). Peer-reviewed (C-gold) manual contours were used as the reference standard to validate auto-contoured GTVs (C-auto) and mean manual contours (C-manual) from two expert clinicians (C1 and C2). Multiple geometric metrics, including the Dice similarity coefficient (DSC), were used for quantitative validation. A DSC $\geq$ 0.7 was deemed acceptable. Inter- and intra-variabilities among the manual contours were also validated. The two-dimensional contours were then reconstructed in three dimensions for GTV volume calculation, comparison and three-dimensional visualisation.

Results: The mean DSC between C-gold and C-auto was 0.79. The mean DSC between C-gold and C-manual was 0.79 and that between C1 and C2 was 0.80. The average time for GTV auto-contouring per patient was 8 min (range 6–13 min; mean 45 s per axial slice) compared with 15 min (range 6–23 min; mean 88 s per axial slice) for C1. The average volume concordance between C-gold and C-auto volumes was 86.51% compared with 74.16% between C-gold and C-manual. The average volume concordance between C1 and C2 volumes was 86.82%.

Conclusions: This newly designed MRI-based auto-contouring software tool shows initial acceptable results in GTV delineation of oropharyngeal and laryngeal tumours using FCLSM. This auto-contouring software tool may help reduce inter- and intra-variability and can assist clinical oncologists with time-consuming, complex radiotherapy planning.

Key words: Automatic delineation; head and neck GTV; magnetic resonance imaging; pharyngeal and laryngeal tumours; radiotherapy treatment planning; volume calculation and 3D visualisation

Introduction

The widespread implementation of intensity-modulated radiotherapy has allowed improved conformity of high dose radiation to the gross tumour volume (GTV) and planning target volume. By minimising the dose to organs at risk, this aims to improve late toxicity [1,2] and has generated renewed interest in dose-escalation strategies. However, one concern with modern highly conformal techniques is the potential for geographical misses and the accurate definition of target volumes is critical. Clinician voluming time and the complexity of this process have also increased significantly as a result [3].

In recent years, magnetic resonance imaging (MRI) linear accelerators [4,5] have been developed to integrate MRI in radiotherapy planning and allow more accurate identification of tumour and normal structures. Delineation of the

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target volumes, especially tumour delineation, is still done manually by clinicians and is time consuming and open to inter- and intra-observer variations [6]. The oropharynx and larynx regions, due to their geometric variability and non-convex form, are examples of areas at risk of this [7]. When treating with radical intent using highly conformal modern radiotherapy techniques this poses challenges and scope for potential errors. Reproducible automatic contouring programmes have the potential to reduce the risk of inter- and intra-observer variability [8].

Administration of gadolinium contrast before obtaining a T1-weighted MRI scan enhances the vasculature and gross tumour, thus significantly improving soft tissue contrast, margin definition and therefore accuracy. Despite this, issues such as tumour necrosis, anatomical and geometric variability, diffused boundaries and scan artefact can make GTV contouring, manual or computer-automated, a challenging task.

In recent years, automatic delineation tools [9–11] have been developed and validated using atlas-based techniques for the segmentation of normal anatomical structures from the head and neck region. This aims to improve time, efficiency and reduce variations when compared with manual delineation. It is, however, not feasible to develop an atlas-based approach for auto-contouring of pathological disease [12]. Different non-atlas-based techniques have been developed for semi-automatic or automatic delineation of head and neck GTV using MRI [13–17]. Publications relevant to oropharyngeal and laryngeal tumours are summarised below.

Two semi-automated tumour volume measurement methods [16] based on seed growing and region deformation are validated on 16 patients with tongue tumours from MRI. These techniques showed satisfactory contouring results but required manual interaction to place seed points. An auto-contouring technique for the extraction of tongue tumours with the help of T1-weighted and T2-weighted MRI is proposed in [17]. In this technique, contouring is applied from the coarse to fine level with selection of five features of tumour regions. This technique was tested on only 16 axial MRI slices as compared with 102 slices in this work.

The intent of this work was to develop a novel approach for auto-contouring of oropharyngeal and laryngeal GTV from gadolinium-enhanced T1-weighted MRI axial slices with three-dimensional reconstruction and volume calculation followed by validation against the current standard manual approach. To the best of our knowledge this is the first automatic tool developed and validated against a manual approach for the delineation of oropharyngeal and laryngeal GTV using gadolinium-enhanced T1-weighted MRI. This tool may help reduce inter- and intra-variability and can assist clinical oncologists with time-consuming, complex radiotherapy planning.

Materials and Methods

Data Acquisition

This was a cross-sectional study with retrospective imaging data. Ten patients previously treated with radical chemo-radiotherapy for stage II/III head and neck squamous cell carcinoma (six oropharynx and four larynx) were randomly selected and included. MRI scans for each patient had been carried out during formal staging work-up pre-treatment. These MRI scans were acquired and processed retrospectively using the automatic contouring tool.

All MRI DICOM files were processed. Scans were obtained from three different 1.5T MRI scanners, namely Magnetom Avanto from Siemens, Intera Neuro coils from Philips Medical Systems and Signa HDxt from GE Medical Systems. The MRI scans were undertaken pre- and post-intravenous gadolinium contrast and were acquired after 15–20 min of intravenous injection of 0.1 ml/kg. The range of other imaging parameters were 3–5 mm slice thickness, 3.3–6 mm spacing in between slices, 9.06–20 ms echo time, 542–1066 ms repetition time, 90–150° flip angle, $0.43 \times 0.43 - 0.94 \times 0.94$ mm in-plane resolution (pixel spacing), $256 \times 256 - 512 \times 512$ acquisition matrix and 97.65–221 Hz/pixel bandwidth.

Of the 10 MRIs assessed, 102 axial slices contained gross tumour.

The MRI scans not only showed variations in the size and shape of the tumour regions, but also variability in contrast uptake, ill-defined margins and artefact presence. Typical axial slices used to test the auto-contouring tool are shown in Figure 1.

Auto-contouring Software Tool

The segmentation framework using this novel and fully automatic contrast enhanced T1-weighted MRI auto-contouring tool for oropharynx GTV in one patient was presented in [18,19]. Gadolinium-enhanced T1-weighted MRI is the preferred imaging modality to define tumour spread for oropharyngeal and laryngeal tumours [20,21] compared with unenhanced (normal) T1, proton-density and T2 MRI, due to its significantly higher contrast-to-noise ratios for the primary tumour and lymph nodes and it significantly improves soft tissue contrast and tumour margin definition.

This paper improves the segmentation framework presented in [18,19], in terms of pre-processing, post-processing techniques and new algorithm for the detection of pharynx region, to assess the tool further in oropharynx and larynx GTV, including three-dimensional reconstruction and volume calculation.

Compared with the initial framework [18,19], additional pre-processing techniques, such as histogram equalisation and log-exponential transform, are applied to the MRI slice to increase the contrast and to reduce noise. The intensity inhomogeneity present in the MRI slice is reduced using a local entropy minimisation technique with modifications for adaptive knot spacing. Furthermore, the pharynx region is detected using a fuzzy rule-based system. Two fuzzy rules based on the intensity and the location of the pharynx region are created for pharynx region detection. Furthermore, as in [19], the information on the detected pharynx region is used in fuzzy c-means clustering for initial segmentation of the pre-processed MRI slice into five clusters. The

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