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Investigating the Feasibility of MRI Auto-segmentation for Image Guided Brachytherapy

A feasibility study has been performed to investigate the viability of applying auto-segmentation methods to the delineation of regions of interest (ROIs) in the treatment of cervical cancer using Image Guided Brachytherapy (IGBT). The introduction of auto-segmentation in IGBT aims to improve outlining consistency while improving patient experience by reducing the time taken to plan treatments. An anonymised database of MRI images and corresponding clinical ROI outlines was curated, categorised by brachytherapy treatment applicator type. This database was then used to train and test an auto-segmentation model to contour the Bladder using three established algorithms, U-Net, SegNet and PSPNet. Quantitatively the U-Net model was found to produce contours geometrically closest to the original manual contours with a mean Dice Similarity Coefficient (DSC) of 0.942 compared to 0.919 and 0.879 for SegNet and PSPNet respectively and a mean Mean Distance to Agreement (mDTA) value of 0.46mm compared to 0.66mm and 0.89mm for SegNet and PSPNet. Visual assessment of the resulting contours demonstrated good agreement for the U-Net and SegNet produced outlines, particularly in the region of clinical significance, with greater variations seen at the extremities of the contour. In conclusion this feasibility study has shown that auto-segmentation methods can be applied to MRI IGBT contour delineation with a method established to facilitate further investigations in the application to all clinical ROIs and brachytherapy applicator types.

Keywords:
Image Guided Brachytherapy, auto-segmentation, MRI.

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INTRODUCTION

Manual contouring of organs at risk (OARs) and target volumes is standard practice for radiotherapy treatment planning at most clinical centres [1, 2]. Manual delineation is time consuming, subjective and cumbersome, with its ease dependent on the efficiency of the contouring tools available [3, 4]. This manual contouring is a significant source of variability within the treatment planning process due to inter or intra-observer variations [1, 2, 5, 6].

Brachytherapy is a radiotherapy treatment that uses sealed radioactive sources to treat cancers by placing the sources close to, or within the tumour. This allows a high radiation dose to be delivered to the tumour, and reduces the dose received by the surrounding healthy tissues when compared to conventional external beam radiotherapy (EBRT) [7, 8]. At Velindre Cancer Centre the Image Guided Brachytherapy (IGBT) process for cervical cancer uses an MR safe intracavitary Venezia applicator (Elekta AB, Sweden). The Venezia applicator comprises an Intrauterine Tube (IUT) and two Lunar Ovoids. The IUT is inserted into the patient's uterus through the cervix under ultrasound image guidance and the lunar ovoids are positioned within the vagina, flush against the cervix.

Our current clinical brachytherapy planning process, from Magnetic Resonance Imaging (MRI) to treatment, typically takes two to three hours. One of the more time consuming aspects is the outlining of the tumour and OARs on the MRI images, locally taking on average 55 minutes [2, 4]. As brachytherapy utilises the inverse square law the dose falloff from a source results in steep dose gradients across surrounding OARs. Therefore a slight difference in target volume outlining can have significant impact on surrounding OAR toxicity or tumour coverage [9].

IGBT for cervical cancer has advanced to planning on MRI datasets alone, with no CT necessary due to the lack of requirement for electron density information [10]. Although MRI images have significantly improved soft tissue contrast compared to CT images they are also subject to increased variability across image acquisitions which causes auto-segmentation challenges [2]. There was little evidence found in the literature of the use of auto-segmentation for brachytherapy, particularly for gynaecological cancers with MRI.

MATERIALS AND METHODS

IGBT with paraxial MRI started at Velindre Cancer Centre in late 2014 with over 160 patients treated since then, totalling over 460 outlined image sets. Since 2014 we have used a varying range of brachytherapy treatment applicators by which the image sets have been categorised. The applicator type chosen for clinical insertion can be dependent on disease location and/or patient anatomy. The anonymised outlined MRI image sets were used to establish a 'gold standard' database on which to train and develop the auto-segmentation solution.

The clinical MRI dataset is in the form of DICOM image files and DICOM RSTRUCT files which store the outlined regions of interest (ROIs). For cervical cancer IGBT these are the target volumes of Cervix, Gross Tumour Volume (GTV) and the High Risk Clinical Target Volume (HR-CTV), which is created as a union of the GTV and Cervix. The OARs outlined are the Bladder, Bowel and Rectum. Once collated, the ROI naming convention standardised and the datasets anonymised these were converted from DICOM files to NIfTI files and subsequently into PNG image files and masks for each ROI.

Existing python code for a range of established auto-segmentation algorithms, including SegNet, Unet and PSPnet, was then adapted to suit this database including image orientation and required number of ROIs [11, 12]. The database was split into training and testing subsections with 90% for training and 10% for testing. For this proof of concept stage the model was primarily trained and tested on the bladder as this is typically the most well defined of these ROIs with greatest contrast at the organ boundaries.

In this feasibility study the Venezia applicator database was used for the training of each of the auto-segmentation models as this was both the largest dataset and the current clinical applicator set used for the majority of patients. The results will later be tested on the Multi-Channel Vaginal Applicator (MCVA) dataset to test if the trained model is independent of applicator or needs to be trained per applicator type. As the applicators are inserted into the patient they have the potential to deform the ROIs and therefore it may be that the trained model is not transferrable between database subsets.

RESULTS

For the bladder there was greater than 2000 PNG image files in the Venezia Applicator dataset. This is equal to each slice with a bladder outline defined on the 104 clinical patient MRI scans. In the 10% testing subset a total of 217 slices were output which equated to 10 full bladder ROI contours.

The Dice Similarity Coefficient (DSC) results and mean Distance to Agreement (mDTA) for each of the 10 patients for the SegNet, U-Net and PSPNet auto-segmentation models are outlined in Tables 1 and 2 respectively. The DSCs were calculated using Eq. 1 where A and B represent the two contour sets, the resulting auto-segmentation model contour and the original manual clinical contour, where $|A \cap B|$ is equivalent to the intersection of the contour sets. For DSC, a measure of overlap, a value of 0 indicates no overlap between the contours and 1 is a perfect overlap. The distance to agreement (DTA) is defined as the shortest distance from a point on the surface of one contour (A) to the surface of another (B). The Mean distance to agreement (mDTA) is the mean of all the DTA distances, where the smaller the mDTA the greater the similarity between the two contour sets.

$$(1)\quad DSC = \frac{2 \times |A \cap B|}{|A| + |B|}$$

It can be seen that the DSC values ranged from 0.849 to 0.955 across all model types with the greatest mean DSC for U-Net (0.942, range: 0.924-0.955), then SegNet (0.919, range: 0.877-0.940) and lastly PSPNet (0.879, range: 0.902-0.849). Similarly the U-Net model was found to produce the lowest mean mDTA value, 0.456mm, compared to 0.662mm for Segnet and 0.894 for PSPNet.

Patient	Auto-Segmentation Model		
	SegNet	U-Net	PSPNet
1	0.917	0.942	0.863
2	0.909	0.924	0.890
3	0.930	0.936	0.883
4	0.924	0.948	0.862
5	0.877	0.953	0.882
6	0.938	0.946	0.902
7	0.940	0.955	0.902
8	0.903	0.926	0.849
9	0.928	0.946	0.866
10	0.928	0.940	0.892
Mean	**0.919**	**0.942**	**0.879**

Table 1: DSC values for Bladder ROIs for the three different Auto-Segmentation models

Patient	Auto-Segmentation Model		
	SegNet	U-Net	PSPNet
1	0.691	0.476	1.049
2	0.617	0.500	0.756
3	0.467	0.477	0.807
4	0.509	0.432	0.906
5	1.822	0.740	1.480
6	0.377	0.330	0.610
7	0.487	0.345	0.727
8	0.608	0.474	0.944
9	0.485	0.339	0.839
10	0.562	0.443	0.820
Mean	**0.662**	**0.456**	**0.894**

Table 2: mDTA values (mm) for Bladder ROIs for the three different Auto-Segmentation models.

Output files were initially produced as PNG mask files. These were converted to DICOM RT structure files containing each auto-segmentation model contour as well as the original clinical Bladder outline. The resulting structure files were then viewed in the clinical treatment planning system, Oncentra Brachy (Elekta AB, Sweden), overlaid on the original MRI images. Fig.2a & Fig.2b show the axial and sagittal views respectively of the bladder contours for the clinical and three subsequent auto-segmentation models for patient two. As well as having the lowest mean DSC values the produced PSPNet contours were visually assessed, by a clinical scientist authorised in IGBT OAR review and plan checking, to be clinically unsuitable due to the pixelated nature of the generated outlines.

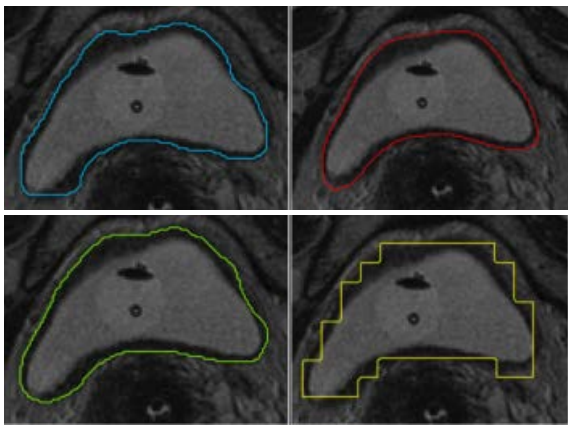

Fig. 1 : Axial Bladder slices for the Clinical (Blue) and SegNet (Red), U-Net (Green) and PSPNet (Yellow) auto-segmentation models for Patient 2.

Both the SegNet and U-Net generated contours were noted to be clinically acceptable for the majority of axial slices, particularly in the mid region of the ROI. However, greater differences were seen compared to the clinical contours at both the superior and inferior extremities of the volume, particularly at the superior aspect of the bladder. It can be seen in Fig.2b that both the SegNet and U-Net contours have failed to outline the apex aspect of the bladder which is raised due to the presence of the catheter tube. The SegNet contour, seen in Red, has also inadvertently outlined some regions of bowel superior to the bladder. For Brachytherapy this may not be clinically significant as the doses reported to the bladder are the highest dose to 2cc (D2cc), and are therefore in the region closet to the treatment applicators within the uterus, typically adjacent to the mid-section of the bladder.

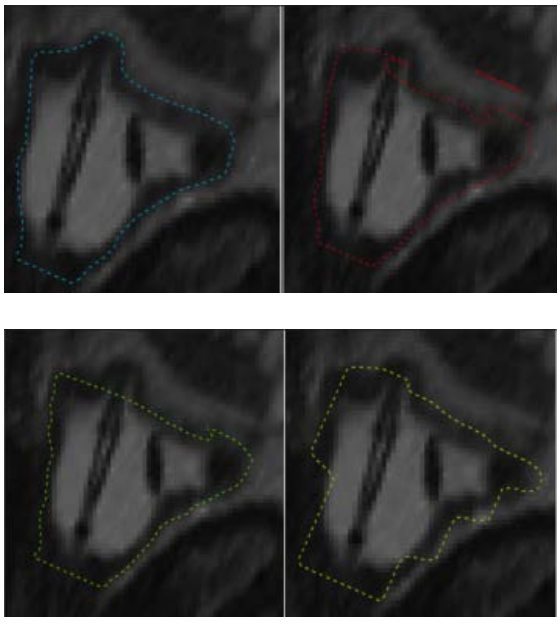

Fig. 2: Sagittal Bladder slices for the Clinical (Blue) and SegNet (Red), U-Net (Green) and PSPNet (Yellow) auto-segmentation models for Patient 2.

DISCUSSION

At this stage preliminary results have shown the possibility to utilise auto-segmentation methods for MRI IGBT cervical cancer treatments. The results have shown that bladder outlines of an acceptable clinical standard in the high dose region can be produced. For this ROI the U-Net and SegNet auto-segmentation algorithms have shown promise and it is anticipated further refinement of the algorithm training will see greater accuracy in the subsequent contours.

This feasibility study has produced a collated database of anonymised IGBT MRI images with standardised ROI naming and a consistent MRI protocol, categorised by brachytherapy applicator type. Although initial results are limited to one ROI a method of data processing, auto-segmentation model training and testing has been established which can now be expanded to include all relevant ROIs and applicator types.

The aim of implementing auto-segmentation into the clinical environment is to both reduce manual outlining variability while also reducing the time taken to produce clinically acceptable contours. This envisioned efficiency aims to improve patient experience by reducing the time the patient has to wait on the ward, with the applicators inserted and unable to move, while the treatment is planned. Increased consistency in outlining by minimising human variation will consequently increase the accuracy and consistency of dose reporting. The auto-segmented contours, such as those produced in this feasibility study, could with minor manual adaptions still lead to significant time savings in the IGBT clinical pathway.

Auto-segmented contouring quality can be quantified in both spatial accuracy and dose calculation accuracy, with each highly dependent on the other [2]. Although spatial accuracy is primarily evaluated in the literature and in this feasibility study to date uncertainties in patient and applicator positioning and anatomical changes may mean that deviations in contours spatially may not have the anticipated outcome on dose distributions and consequently treatment efficacy [2]. Dose assessments to understand the clinical significance in any outlining variations will further inform algorithm requirements.

Conflicts of interest
The authors declare no conflict of interest.

Research approval
This research project is approved by the HRA and Health and Care Research Wales (HCRW), IRAS project ID 300935, REC reference: 21/HCRW/0033.

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