A self-tuned graph-based framework for localization and grading prostate cancer lesions: An initial evaluation based on multiparametric magnetic resonance imaging

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ABSTRACT

Multiparametric magnetic resonance imaging (mpMRI) has been established as the state-of-the-art examination for the detection and localization of prostate cancer lesions. Prostate Imaging-Reporting and Data System (PI-RADS) has been established as a scheme to standardize the reporting of mpMRI findings. Although lesion delineation and PI-RADS ratings could be performed manually, human delineation and ratings are subjective and time-consuming. In this article, we developed and validated a self-tuned graph-based model for PI-RADS rating prediction. 34 features were obtained at the pixel level from T2-weighted (T2W), apparent diffusion coefficient (ADC) and dynamic contrast enhanced (DCE) images, from which PI-RADS scores were predicted. Two major innovations were involved in this self-tuned graph-based model. First, graph-based approaches are sensitive to the choice of the edge weight. The proposed model tuned the edge weights automatically based on the structure of the data, thereby obviating empirical edge weight selection. Second, the feature weights were tuned automatically to give heavier weights to features important for PI-RADS rating estimation. The proposed framework was evaluated for its lesion localization performance in mpMRI datasets of 12 patients. In the evaluation, the PI-RADS score distribution map generated by the algorithm and from the observers’ ratings were binarized by thresholds of 3 and 4. The sensitivity, specificity and accuracy obtained in these two threshold settings ranged from 65 to 77%, 86 to 93% and 85 to 88% respectively, which are comparable to results obtained in previous studies in which non-clinical T2 maps were available. The proposed algorithm took 10s to estimate the PI-RADS score distribution in an axial image. The efficiency achievable suggests that this technique can be developed into a prostate MR analysis system suitable for clinical use after a thorough validation involving more patients.

1. Introduction

Prostate cancer is the most common non-skin cancer in the United States with an estimated of 220,800 new cases in 2015 [1]. In Hong Kong, prostate cancer was the third most common cancer in men and accounted for 11.3% of all new cancer cases [2]. Fortunately, more than 90% of all prostate cancers are diagnosed at the localized stage and five-year survival rate is almost 100% for men diagnosed with localized cancer [3]. Hence, it is important for men with elevated risk to be periodically screened. The first-line screening tests include Digital Rectal Examination (DRE) and serum Prostate Specific Antigen (PSA) tests. If the DRE or PSA result is suspicious for cancer, transrectal-ultrasound-guided (TRUS-guided) biopsy is performed. Since prostate cancer lesions are difficult to be seen in ultrasound, TRUS-guided biopsy is not a procedure that targets suspicious lesions but a systematic technique that samples prostate regions in which tumours occur most frequently [4]. As a result, TRUS-guided biopsy missed 20 – 35% of detectable lesion in the first biopsy [5–8]. To increase the cancer
hemorrhage and prostatitis, may mimic cancer in T2W images [14]. The apparent diffusion coefficient helps localize cancer as the mean water path length is shortened by cell membranes of malignant lesions. The apparent diffusion coefficient measured by DW imaging is the most widely used MR sequence for determining local tumor aggressiveness, such as post-biopsy membranes of malignant lesions. The score is shown at the bottom of each image.

Fig. 1. Outlines of prostate lesions by two radiologists on T2W, ADC and DCE images. Each row shows the contour drawn by a radiologist. 7 DCE images were acquired sequentially (Fig. 2) and the one with the maximum enhancement is shown. The radiologists assigned a PI-RADS score to each lesion shown in the three sequences. The score is shown at the bottom of each image.

Multiparametric MRI (mpMRI) combines anatomic and functional imaging techniques and has been shown to have high sensitivity and specificity in cancer localization [10–12]. Consensus guidelines have been established for the use of mpMRI [13], which recommended the combination of T2-weighted (T2W) images with at least two functional MRI techniques, typically the dynamic contrast enhanced (DCE) and diffusion-weighted (DW) MRI. T2W MR imaging is the most widely used MR sequence for anatomy visualization. It has high tissue contrast and spatial resolution for visualization of zonal anatomy and tumours, which typically appears as homogeneous low-intensity regions in the peripheral and transition zones [13] (Fig. 1(a)). However, the specificity of T2W imaging is limited since benign abnormalities, such as post-biopsy hemorrhage and prostatitis, may mimic cancer in T2W images [14]. DW imaging measures the Brownian motion of water molecules and can help localize cancer as the mean water path length is shortened by cell membranes of malignant lesions. The apparent diffusion coefficient (ADC) characterizing the amount of diffusion is calculated from multiple DW images, and are typically displayed as a parametric map with lesions appearing hypointense due to reduced water diffusion [Fig. 1(b)] [10,15,16]. The addition of DW imaging to T2W imaging significantly improves the sensitivity and specificity of cancer detection [13,15]. Prostate cancer tissue can also be characterized by DCE-MRI as the increased vascularity of cancer leads to early hyper-enhancement and rapid washout of the gadolinium contrast agent (Fig. 2) [17,18]. High temporal resolution DCE-MRI is typically performed to characterize the rate of uptake and washout of the contrast agent. When used alone, DCE-MRI does not have a high sensitivity in cancer detection [11]. However, the sensitivity of T2W imaging is shown to increase significantly when combined with DCE-MRI [11,19].

Although prior studies have been performed to investigate the use of mpMRI for prostate lesion detection and localization [10,11,15,19–24], most studies involved visual identification of lesions from 6 to 30 coarse regions in the prostate instead of pixel-accurate lesion delineation. The detection yield, repeated biopsies are required, leading to increased anxiety pain and morbidity for patients. Thus, sensitive image-based tools allowing for precise lesion localization are required in the development of targeted sampling strategies.

The widespread use of PSA screening since the early 90’s has led to a higher detection rate of localized and less aggressive tumours [9]. The development of focal therapies, such as cryotherapy and high-intensity focused ultrasound, has provided options for localized tumours to be treated with a lower risk of morbidity. Delineation of tumours is required for the administration of these therapies in order to minimize damage to the surrounding healthy tissues and organs. In addition to tumour localization, risk assessment is also important to identify suitable candidates for focal therapies.
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