Localizing prostate brachytherapy seeds with SGM

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Introduction

Brachytherapy is a common radiation treatment option for prostate cancer, in which many small radioactive seeds are implanted into the prostate gland under image guidance [1]. Precise knowledge of the prostate volume and the distribution of the seeds are required for accurate radiotherapy dosimetry. Imaging modalities like 2D X-ray or computed tomography allow precise seed localization but do not offer the soft-tissue contrast for accurate depiction of the prostate. MRI offers superior soft tissue contrast of the prostate but radioactive seeds produce local susceptibility changes and thus hypo-intensities in gradient echo MR images. These signal voids may be confused with other structures, such as blood vessels, making distinction sometimes difficult. Therefore, the use of a combined X-ray and MR-system (XMR) has been proposed for the visualization of brachytherapy seeds (from X-ray) overlaid to the MR-image of the prostate through registration [2].

In this work we applied susceptibility gradient mapping (SGM) using the original resolution for accurate seed localization, which can be overlaid onto MR data of the prostate. Furthermore, we investigated the strength of the induced susceptibility gradient as a basis for dosimetry.

Method

A SGM technique based on calculating the echo-shift in the k-space, k_s of gradient-echo data by post-processing has been presented for positive visualization of iron-oxide contrast agent [3]. This was applied to a phantom of gelatin containing non-radioactive prostate seeds and Perspex copies to mimic an alternative source of hypo-intensity. The prostate seeds were placed in groups of 1 up to 5 seeds and gradient echo MR images were obtained on a 1.5T system (Philips, Achieva) with: resolution 1.4 x 1.0 x 1.6 mm^3; FOV = 355 x 250 x 112 mm^3; FA = 8°; NEX = 2; TE/TR = 4.6/7.5.

In-vivo data was acquired with the same parameters, in an XMR suite that allowed accurate registration using a table that moved between both systems [2]. The post-processing SGM technique was used to calculate a map of k_s for each direction and the magnitude $|k_s|$ was used as measure for the induced susceptibility gradient. The gradient-echo images were used to segment the prostate and clusters of positive contrast were formed from the parameter map within this region by excluding values for $|k_s| < 5\sigma_{ks}$. The number of seeds located within each cluster for the *in-vivo* case was validated using registration information from the XMR suite.

Results and Discussion

The positive contrast by mapping $|k_s|$ from *in-vitro* data showed hyper-intensities relating to the prostate and not the Perspex seeds (Fig.1b). A plot of the $|k_s|$ integrated over each positive cluster provided a linear correlation (R^2=0.99) to the number of actual prostate seeds within each group (Fig.1).

The negative contrast was used to delineate the prostate while the hyper-intensities from SGM related to the seed locations (Figs.2a-b). The arrow in Figure 2c points to an example of SGM used in overlay to differentiate from low signal intensity in the negative contrast from other sources. Integration of $|k_s|$ over the clusters of positive contrast in the parameter map compared with the seed locations as determined by use of the XMR suite again showed a linear relationship (R^2=0.94) (Fig.2d). Both *in-vitro* and *in-vivo* there are instances of non-zero values in the integral of $|k_s|$ relating to zero prostate seeds. This is due to alternative sources of susceptibility difference, such as those at air-to-tissue surfaces and might be segmented by taking into account the size and direction of the k_s [4].

Figure 1. MRI of phantom produced negative contrast (a) and SGM applied to data provides positive contrast (b). A single prostate seed is detected (arrow). Plot of $|k_s|$ integral correlates with number of prostate seeds.

An iterative closest point (ICP) algorithm was also used to register the points from X-ray to the point clouds of positive contrast from the $|k_s|$ parameter map. The difference in the location of the seeds after ICP of X-ray points to the point clouds, compared with XMR registration, was (0.5±0.2), (0.4±0.4), and (1.7±0.3) mm in the x-, y-, and z- directions respectively.
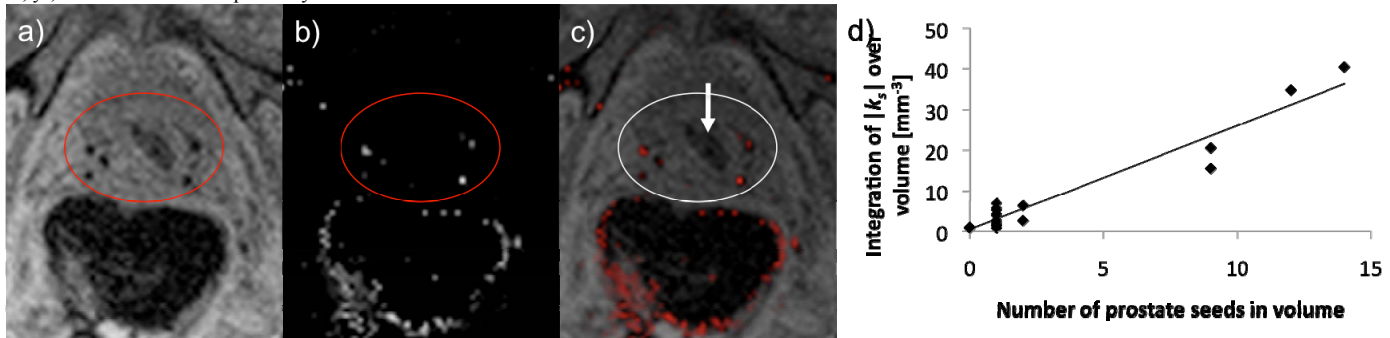

Figure 2. MRI of prostate with post-implantation produced negative contrast (a) from seeds and other sources but allows accurate prostate depiction. SGM applied to data provides positive contrast (b) and overlay (in red) onto the original image (c) improves accurate seed localization. As *in-vitro*, a plot of $|k_s|$ integral shows a linear relationship with the number of seeds (validated from XMR) in a cluster of positive contrast.

Conclusions

SGM by post-processing has been demonstrated for positive visualization of prostate seeds. Integration of the echo-shift related to the seeds' presence was found to have a linear correlation with the number of prostate seeds. This provides potential for dosimetry solely by MR, utilizing its precision in prostate volume analysis. In the interim registration of points from X-ray to this parameter map was within a pixel of those using XMR. Thus this technique might be applied for registration of points from X-ray in the absence of XMR facilities for confirmation of seed numbers.

References

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