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Prostate brachytherapy

Accuracy of seed reconstruction in prostate postplanning studied with a CT- and MRI-compatible phantom

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Abstract

***Background and purpose*: Postimplant dosimetry of prostate seed implants is usually performed by seed localisation on transversal CT or MR images. In order to obtain reliable dosimetric evaluation data, it is important that seeds are reconstructed accurately. Currently, there is no comparative data available on seed localisation accuracy of CT-and MRI-based reconstructions, mainly due to the lack of a suitable QA tool. In this study, we developed a CT-and MRI compatible prostate phantom to investigate the intrinsic accuracy of seed detection for both imaging modalities.**

***Patients and methods*: A 60 seed geometry was created according to a clinically meaningful plan, including rotated and shifted seeds. After implantation of the seeds in the phantom, CT and MRI scans with 3, 4 and 5 mm slice thickness were performed. The seed locations were reconstructed in the treatment planning system and compared with the known reference positions.**

***Results*: Due to the comparable density and relaxation times of the phantom material to prostate tissue, the seeds are visualised similarly as on real patient images. The observed mean reconstruction uncertainties were in general smaller for CT (0.9 ± 0.6, 0.9 ± 0.6, 2.1 ± 0.8 mm on 3, 4 and 5 mm scans, respectively), than for MRI (Philips 1.5T: 2.1 ± 1.4, 1.6 ± 1.2, 1.9 ± 0.9 mm on 3, 4 and 5 mm scans, respectively, and Siemens 1.5T: 2.3 ± 0.8, 2.0 ± 1.6, 1.6 ± 0.8 mm on 3, 4 and 5 mm scans, respectively).**

***Conclusions*: For our clinical sequences of both CT and MRI, the mean deviation of the reconstructed seed positions were all within acceptable limits for clinical use (<2.3 mm). The phantom was found to be a suitable quality assurance tool to assess the reliability and accuracy of the seed reconstruction procedure. Moreover, as the phantom material has the same imaging characteristics as real prostate tissue, it is a useful device to define proper MRI sequences.**

Keywords: Quality assurance; Prostate seed implant; Phantom

Postimplant analysis following permanent seed implantation in prostate is an important step in the treatment process, as it provides the necessary feedback to ensure the quality of the implant. Not only it helps to improve the implantation technique, it also provides dosimetric data to evaluate treatment outcome and serves to suggest the need for additional treatment in case of underdosage of the target [16,17,28]. Therefore, it is of utmost importance that the dosimetric evaluation is performed accurately.

Postimplant dosimetric evaluation is usually performed on transversal CT and/or MR images acquired 4–6 weeks after implantation [10,17]. The reliability and accuracy of the dosimetric postplanning depends on many factors, the most important being the accuracy of target delineation and seed localisation. In that respect, both CT and MRI based techniques have their benefits and shortcomings. MRI is known to provide superior image quality for target delineation than CT. Several studies have reported an overestimation in delineated prostate volume ranging from 20 to 40% with CT compared to MRI [7,14,21,22]. On the other hand, source detection is easier and faster on CT than MRI as the source signals can be readily identified either manually or with automated seed detection algorithms [1,2,8,26]. For CT, such algorithms are now commonly available on most treatment planning systems. For this reason and due to the fact that few institutes have an MRI scanner at their disposal, the majority of centres currently uses CT for quantitative dosimetric evaluation.

Besides target delineation, seed localisation accuracy is another crucial factor in attaining reliable dosimetric postplanning data. The accuracy of the seed localisation depends in first place on the visualisation characteristics of

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the seeds, which are inherently related to the chosen technique. Reconstruction artefacts in CT images may complicate seed detection, especially if seeds are clustered together or when they are close to calcifications. For MRI, seed detection may be difficult due to the low contrast between the seeds and the surrounding tissue. Moreover, inhomogeneities in the magnetic field may cause distortions in the positions of seed signal voids, resulting in incorrect seed placement. Furthermore, specific image acquisition parameters, such as interslice spacing, may influence the seed reconstruction accuracy. Finally, inaccuracies may occur due to calibration uncertainties in the image acquisition (e.g. scaling errors).

The intrinsic seed localisation uncertainty of the CT and MRI based reconstruction technique has not been investigated in detail and comparative data between both techniques are not available. This is partly due to the lack of suitable QA tools. Some commercial gel-based phantoms have been employed for seed detection tests with X-ray films, ultrasound and CT, but these phantoms are not tissue-equivalent for MRI and the seed coordinates cannot be determined accurately [1,12,25]. Some groups have developed solid phantoms containing seeds at known positions for seed detection tests for CT and X-ray films [19,24]. However, the solid material of the phantom surrounding the seeds does not produce any signal on MRI. Hence, the seeds cannot be distinguished as signal voids.

In this study, we present a QA phantom simulating the prostate that can be used both on CT and MRI scanners. With this phantom, we investigate the intrinsic seed localisation accuracy of both imaging modalities. The influence of interslice spacing on the accuracy is studied and compared for CT and MRI. The impact of seed identification difficulties due to anatomical heterogeneities in the prostate is excluded.

Materials and methods

A phantom is constructed and implanted with inactive seeds at predefined positions. The principle is that, after scanning the phantom, the seed positions can be reconstructed and compared with these known reference positions.

Phantom design

Construction materials

The prostate phantom consists of a rectangular PMMA container placed on a stabilising plate with spirit level. The container holds an agarose gel fabricated from a solution of 4% agarose powder (SeaKen®, EEO = 0.16–0.19) in distilled, deionised water. After magnetic stirring and heating, the solution polymerises into a semi-solid substance [15]. This tissue-equivalent material fulfils the following requirements:

(a) Agarose has a comparable density to prostate tissue, which permits adequate and realistic seed visualisation on CT. The densities were derived from the Hounsfield units (HU) in the treatment planning system. The HU-density conversion curve was determined by CT-scanning a calibration phantom containing several different materials with a well-known density. The Hounsfield units were measured for five different prostates and for five agarose slabs (10 random pixels in each). The derived density values (mean $\pm$ 1 SD) were found to be 1.032 ± 0.011 versus 1.036 ± 0.022 for agarose, respectively, prostate.

(b) Agarose possesses similar visualisation characteristics in MRI as prostate tissue. This is important as imaging characteristics may influence the seed visualisation (size of signal void, position distortions due to field inhomogeneities) and hence the localisation accuracy. As the seed visibility strongly depends on the MRI sequence chosen, the seed imaging in the tissue-equivalent material should be similar to real prostate tissue regardless of the scanning parameters. The imaging characteristics are determined by the relaxation times of a material. The $T1$ and $T2$ relaxation times of the agarose gel were determined using a 1.5T Philips Intera MRI scanner. The method used to obtain a pure $T1$-image ($T1$-map) relies on a mathematical manipulation of separately obtained images with a different known $T1$ influence (here two images with a different inversion time). Namely, a mono-exponential fit is performed on the pixel values of the object at these different inversion times to determine the pixelwise $T1$-value. Pure $T2$-images ($T2$-maps) are calculated from the images of a multi-echo series (here 12 echoes) by performing a mono-exponential fit to the pixel values of the object at these different echo times [3,18].
The measured relaxation times of the agarose gel were found to be $T1 = 1207 \pm 168$ ms and $T2 = 66 \pm 9$ ms. These values are close to the relaxation times $T1 = 1074 \pm 117$ and $T2 = 104 \pm 14.6$ measured with the same technique for a human prostate, and to relaxation time values reported in literature for prostate tissue with a typical $T1 = 1317 \pm 85$ ms and $T2 = 88 \pm 0$ ms at 1.5 T [5].

(c) The material is sufficiently solid to allow the accurate implantation of dummy seeds at predefined positions. Increasing the agarose concentration above 4% does not significantly strengthen the gel any further. Besides, this would reduce the MRI relaxation times, resulting in $T1$ and $T2$ values much lower than those in the prostate.

The agarose gel is shaped in square slabs by pouring the hot agarose solution in a mould with dimension $5 \times 50 \times 50$ mm^3. After cooling and solidification of the agarose, the seeds are implanted and the 5 mm thick slabs are placed one behind the other into the container. The agarose is tightly sealed from air using a O-ring closure in order to prevent the agarose to dry out and shrink. This measure guarantees the long-term stability of the enclosed material (after 18 months, there was no visible degradation of the phantom material, nor any change in seed positions). In order to prevent bacterial growth in the medium, the phantom is sterilised by irradiation to 60 Gy.