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BrachyView: Verification of LDR patient plans - Hardware optimisation

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BrachyView: Verification of LDR patient plans - Hardware optimisation

Abstract

BrachyView is a novel in-body imaging system developed with the objective to provide real-time intraoperative dosimetry for low dose rate (LDR) prostate brachytherapy treatments. Seed positions can be reconstructed after implantation by the means of a high-resolution pinhole gamma camera. The obtained dataset is then combined with conventional trans-rectal ultrasound (TRUS) imaging to locate the effective source position within the prostate volume. This study presents a comparison of two data sets containing 96 and 98 I-25 brachytherapy sources and readout by two different pin-hole collimators with 800 m and 500 m, respectively. This study aims to assess the effect on reconstruction of large pinholes which allow for large Field of View (FoV) and statistics of counts on the seed's projections. It was found that 100% of seeds were reconstructed by the means of the 500 m collimator. Results from the 800 m data showed that only 70% of seeds were reconstructed with a total 3D discrepancy of 8.20 mm in respect to CT data and an increased reconstructed position inaccuracy.

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BrachyView: verification of LDR patient plans – hardware optimisation

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Abstract. BrachyView is a novel in-body imaging system developed with the objective to provide real-time intraoperative dosimetry for low dose rate (LDR) prostate brachytherapy treatments. Seed positions can be reconstructed after implantation by the means of a high-resolution pinhole gamma camera. The obtained dataset is then combined with conventional trans-rectal ultrasound (TRUS) imaging to locate the effective source position within the prostate volume. This study presents a comparison of two data sets containing 96 and 98 I-25 brachytherapy sources and readout by two different pin-hole collimators with 800 μm and 500 μm , respectively. This study aims to assess the effect on reconstruction of large pinholes which allow for large Field of View (FoV) and statistics of counts on the seed's projections. It was found that 100% of seeds were reconstructed by the means of the 500 μm collimator. Results from the 800 μm data showed that only 70% of seeds were reconstructed with a total 3D discrepancy of 8.20 mm in respect to CT data and an increased reconstructed position inaccuracy.

1. Introduction

Prostate cancer is a disease by which malignant cells form in the tissues of the prostate gland. Prostate cancer is quickly becoming the most common form of cancer across the globe. Prostate cancer is one of the most commonly diagnosed cancers within Australia, contributing to 24.7% of newly diagnosed cancers [1]. With the current aging population this problem is predicted to continue to rise within the following years, as prostate cancer is most common in elderly males, with 85% of prostate cancer cases being attributed to men above the age of 65 [2]. It is hence of grave importance that common treatment modalities available for prostate cancer treatment can be developed and improved in order to support patients and provide the best care possible.

Common treatments prescribed to patients include radical prostatectomy (RP), involving the removal of the entire prostate gland, external beam radiation therapy (EBRT) consisting in delivery of focused x-ray beams to the treatment area, and finally brachytherapy treatments, either consisting of low dose rate (LDR) or high dose rate (HDR) treatments [3]. Radiation oncologists must carefully evaluate the patient in order to prescribe the most suitable treatment, some clinical measures for determination of patient selection for a treatment includes the grade of the tumour, Gleason score and prostate specific antigen scores (PSA) [4].

LDR brachytherapy is a radiotherapy treatment that is most commonly utilized to treat low grade, slowly proliferating tumours located within the prostate. Permanent radioactive implants are used to

deliver the prescribed dose to the cancerous area, these implants are commonly referred to as seeds and contain I-125 or Pd-103. The use of these specific radionuclides is to ensure a highly conformal dose is delivered to the tumour site, with steep dose gradients utilized to minimize the dose delivered to surrounding healthy tissues and critical organs such as the bladder, urethra and rectum [5]. It is critically important to minimize the dose to surrounding healthy tissues as additional dose can lead to poor patient outcomes with post-operative complications such as sexual dysfunction and urinary symptoms, impacting the quality of life of the patient.

Studies have shown that additional dose to surrounding healthy tissues can result from seed positioning errors during the implantation procedure [6]. Due to possible seed position deviations from those outlined in the treatment planning system it is crucial to re-assess the true positions of the seeds directly after the implantation. Such procedures require the determination of the seeds positions and the resulting dose distribution to be correctly determined in real time and in-vivo. Currently, patient doses are verified utilizing means of post-operative dosimetry such as computerised tomography (CT) or magnetic resonance imaging (MRI) to visualize and reconstruct seed positions [7]. However, this procedure is commonly performed a number of weeks or even months after the procedure. As the desire to optimize and improve the overall treatment of brachytherapy becomes ever more important it is crucial to ensure that a means for real-time intraoperative dosimetry be developed, allowing for real-time localization of seeds with no additional dose delivered to the patient, allowing for intraoperative replanning to ensure adequate coverage of the planned treatment volume and minimization of dose to the organs at risk. CMRP propose the system named BrachyView, the first miniaturised gamma camera able to determine the seeds positions in-vivo and in real-time.

2. Materials and Methods

The BrachyView probe consists of a 1 mm thick cylindrical tungsten collimator, containing three single cone pinholes, as shown in Figure 1. This study utilized two collimators with pinhole diameters of 500 μm and 800 μm to assess the effect of the pinhole diameter on seed reconstruction quality in the presence of a clinically relevant number of seeds, as well as the feasibility to perform reconstruction prior to seed deployment from the treatment needles. Details on the probe architecture and construction structure has been previously presented by Alnaghy [8].



Figure 1. The BrachyView probe covered in a 700 μm kapton tape, in order to ensure no liquid penetration during acquisition.

Two clinical LDR prostate brachytherapy plans were devised containing 98, and 96 seeds (I-125 with an average activity of 0.248mCi and 0.303mCi respectively), implanted into a CIRS prostate gel phantom. TRUS images, manual segmentation and rendering were performed to reconstruct the 3D shape and position of the prostate, utilizing transversal 2.5 mm ultrasound slices.

BrachyView data was acquired for an average of 2.5 minutes after each seed deployment to compensate for the low activity of the seeds. A post implant CT study with O-MAR (orthopedic metal artefact reduction) and scan protocol of 1 mm slice thickness with a 0.5 mm inter-slice acquisition, was completed to provide a reference for comparison of the reconstructed seed positions.

3. Results

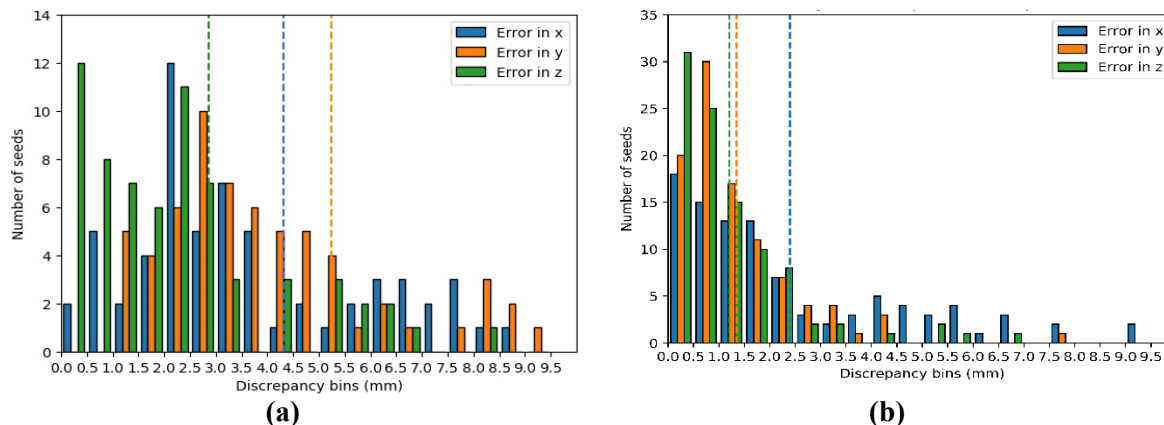


Figure 2. a) CT and BrachyView 800 μm collimator, b) 500 μm collimator reconstructed seed position discrepancies with average discrepancies denoted as dotted lines.

When compared to the seed positions obtained by the CT scan the BrachyView reconstruction showed average discrepancies of 2.4 mm, 1.35 mm and 1.2 mm in the x, y and z reference frames, respectively for the 500 μm collimator. For the 800 μm collimator average discrepancies of 4.3 mm, 5.23 mm and 2.86 mm in the x, y and z reference frames respectively. Only 70% of seeds were reconstructed, when compared to 100% of seeds reconstructed with use of the 500 μm collimator.

The use of the 800 μm collimator leads to larger X, Y and Z discrepancies in respect to the reference data from CT than the 500 μm collimator, as shown in Figure 2. This can be attributed due to the increase in scatter contribution within the images, as well as an increase in projection size during image acquisition. Projection size plays an important role not only in image quality but also subsequently seed reconstruction accuracy.

When seeds are placed in close proximity of one another and a large pinhole is utilized this will ultimately result in a larger projection and may result in overlapping of two or more adjacent projections, inhibiting reconstruction capabilities. This phenomenon was present within the data and is shown in Figure 3. A comparison between the data from the 800 μm and 500 μm collimator including 15 seeds placed at varying heights from the pinholes (within a distance of approx. 5.5cm) was performed in order to determine the difference in projection sizes in the two data sets (Table 1).

It was concluded that the 800 μm collimator data showed a 22% increase in projection size when compared to the data of the 500 μm collimator. The large projection size results in projections overlapping neighbouring seeds, creating great uncertainty in the reconstruction of the centre of mass of the single seed. The overlapping of two seeds projections results in one single projection which is misinterpreted as a single seed with a centre of mass shifted. This leads to the large discrepancies recorded between CT and BracView-800 reconstructed final positions showed in Figure 2. Details of the reconstruction methods have previously been presented [9].

Table 1. 800 μm and 500 μm collimator projection sizes.

	800 μm		500 μm	
	Pixel width (mm)	Pixel height (mm)	Pixel width (mm)	Pixel height (mm)
	1.155	0.825	0.605	0.770
	0.935	0.880	0.605	0.605
	1.320	0.770	0.770	0.605
	1.100	0.715	0.770	0.660
	1.210	1.100	0.770	0.660
	1.045	0.990	0.715	0.495
	1.045	0.880	0.770	0.550
	0.990	0.770	0.825	0.550
	0.935	0.770	0.990	0.715
	1.375	0.825	0.880	0.550
	1.650	1.210	1.210	0.715
Average (mm) ± 0.006 mm	1.160	0.885	0.810	0.625

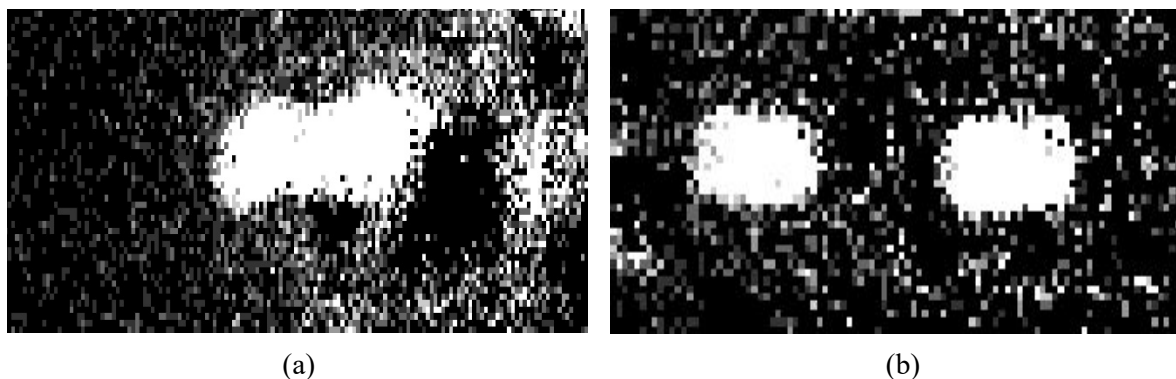


Figure 3. a) Overlapping seed projections with use of the 800 μm collimator, inhibiting accurate delineation of individual seed center of mass for reconstruction, **b)** clear projection definition provided with use of the 500 μm collimator.

4. Conclusions

BrachyView data utilizing an 800 and 500 μm collimator pinhole has been analysed and compared in order to assess the effect on reconstruction capabilities of the system. Results from the 800 μm data showed increased baseline noise from scatter contribution and reconstructed positions with large inaccuracy. Only 70% of seeds have been reconstructed due to overlapping of seed projections which could not be used to identify the individual centre of masses. This is an indicator that the use of the 800 μm collimator for seed reconstruction before seed deployment from treatment needles is not feasible with the current methodology employed.

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