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ORIGINAL ARTICLE

A virtual fluoroscopy system to verify seed positioning accuracy during prostate permanent seed implants

V. Sarkar, A.N. Gutierrez, S. Stathakis, G.P. Swanson, N. Papanikolaou

Department of Radiation Oncology, The Cancer Therapy and Research Center at the University of Texas Health Science Center, San Antonio, TX, USA

Summary

Purpose: *The purpose of this project was to develop a software platform to produce a virtual fluoroscopic image as an aid for permanent prostate seed implants.*

Materials and methods: *Seed location information from a pre-plan was extracted and used as input to in-house developed software to produce a virtual fluoroscopic image. In order to account for differences in patient positioning on the day of treatment, the user was given the ability to make changes to the virtual image.*

Results: *The system has been shown to work as expected for all test cases.*

Conclusion: *The system allows for quick (on average less than 10 sec) generation of a virtual fluoroscopic image of the planned seed pattern. The image can be used as a verification tool to aid the physician in evaluating how close the implant is to the planned distribution throughout the procedure and enable remedial action should a large deviation be observed.*

Key words: brachytherapy, fluoroscopy, implant, prostate cancer

Introduction

Low dose rate brachytherapy with permanent seed implants is a common method employed to treat patients with early-stage prostate cancer [1-3]. Before the actual seed implantation, the physician will typically perform an ultrasound-based volume study. The information thus gathered is used to create a "pre-plan" in which the location of sources is optimized to deliver adequate dose coverage to the prostate while ensuring that sensitive structures such as the bladder, urethra and rectal wall are spared [4-6]. Radioactive seeds are then ordered to reflect the distribution created in the pre-plan. On the day of the implantation, the physician attempts to reproduce the same anatomical setup that was used during the volume study. This is sometimes performed by using a transrectal ultrasound probe to deform the prostate so as to "reshape" the gland to resemble the pre-plan prostate. Even then, variations of the shape of the prostate are not uncommon [7]. Once this positioning has been performed, the seeds are implanted with the aid of a needle guide template and ultrasound guidance in an effort to reproduce the seed pattern created in the pre-plan. As seeds are implanted, the quality of the ultrasound images quickly degrades [8] due to the image artifacts generated by the metal seeds. Thus, there is no easy method of seed identification once they are deposited into the prostate in order to determine the accuracy of seed placement. Most physicians typically use a fluoroscopic system at the completion of the implant to verify seed positioning [9,10]. Unfortunately, a reference image is not available to compare that generated by the fluoroscope screen. By taking an anterior-posterior (AP) projection, physicians rely on their clinical experience to determine whether the seed distribution visually looks adequate. However, it is not possible to tell whether the observed spatial seed distribution matches that of the plan, especially in the AP position of each source since the dimension is lost. In light of this, we sought to solve this problem by creating a virtual fluoroscopy system that uses the three-dimensional seed location information

Correspondence to: Vikren Sarkar, BS. 7979 Wurzbach Road, MC 7889/Radiation Oncology, San Antonio, TX 78229, USA. Tel: +1 210 450 1061, Fax: +1 210 616 5682, E-mail: sarkar@uthscsa.edu

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from the pre-plan and generates a virtual fluoroscopic image displaying the geographical distribution of the planned seeds.

Materials and methods

Each treatment planning system (TPS) uses a different method to archive the information regarding the plan being utilized. For this project, we used the SPOT-PRO™ system [11] from Nucletron (Nucletron Corp., Columbia, MD) to create the prostate seed pre-plans. The seed locations are obtained as part of the report that is created at the finalization of the planning process. Table 1 shows the source positions for a model simple case using 4 needles with 2 seeds in each needle. This information is extracted and used as source data to a ray-tracing algorithm implemented in the Matlab (version 7.6, The Mathworks Inc., Natick, MA) platform. The algorithm creates a virtual fluoroscopy image by simulating an isocentric C-arm fluoroscopic system. Figure 1 shows a flowchart demonstrating the working process of the algorithm. First, the coordinates are normalized so that the center of the implant is the origin. The rotated coordinates are then calculated if the projection is to be created at any angle other than the AP geometry which is considered to be the zero angle. Ray tracing [12] is performed to determine where the shadow of each seed falls on the detector plane and an image is created and displayed in a graphical user interface (GUI). In order to facilitate the comparison, any projection created using an AP projection geometry is overlaid on a generic background showing an x-ray of the pelvic region. The user then has the option of panning, rotating or zooming the projected image so that it matches the actual patient geometry on the day of the implant. Since the dimension of each pixel in the detector plane is set to 1 mm, translations of the seed distribution are calculated by altering the coordinate of each seed by an amount required to produce a translation of the correct magnitude and direction. For rotation, a 2-dimensional rotational matrix is used to map each original seed location to its new position. Finally, for the zoom process, the original distribution is resized and the edges are cropped. All calculations take less than 10 sec on a laptop with an AMD dual-core Turion processor using a 1.9 GHz CPU and 2 GB of RAM.

Table 1. Seed location information

Source Positions Table				
Needle	*Seed*	*x mm*	*y mm*	*z mm*
1	1	42.168	65.332	0.00
1	2	42.168	65.332	–10.00
2	1	102.168	65.332	0.00
2	2	102.168	65.332	–10.00
3	1	42.168	5.332	0.00
3	2	42.168	5.332	–10.00
4	1	102.168	5.332	0.00
4	2	102.168	5.332	–10.00

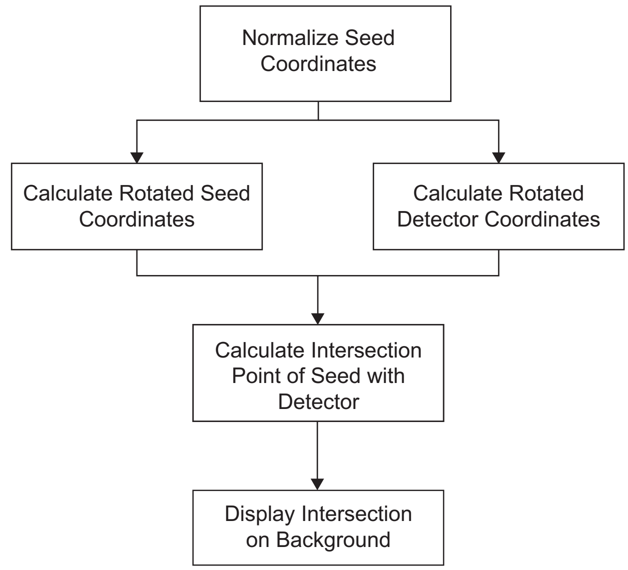

Figure 1. Flowchart demonstrating the virtual fluoroscopy creation process.

Results

Figure 2 shows the computed seed distribution calculated at 3 different angles using optimized seed positions for an actual patient plan. These were not overlaid on any background so that the differences between the projections are clear.

Figure 3a shows a snapshot of the GUI depicting a distribution overlaid on the background before any changes are applied to the distribution. The same distribution after it has been panned (Figure 3b), rotated (Figure 3c) and zoomed (Figure 3d) is shown.

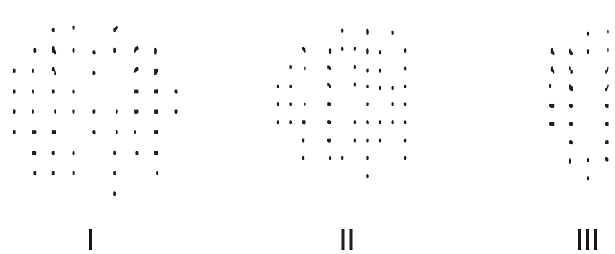

Figure 2. Virtual fluoroscopy images obtained using an anterior-posterior (I), left anterior oblique (II) and left lateral (III) imaging geometry.

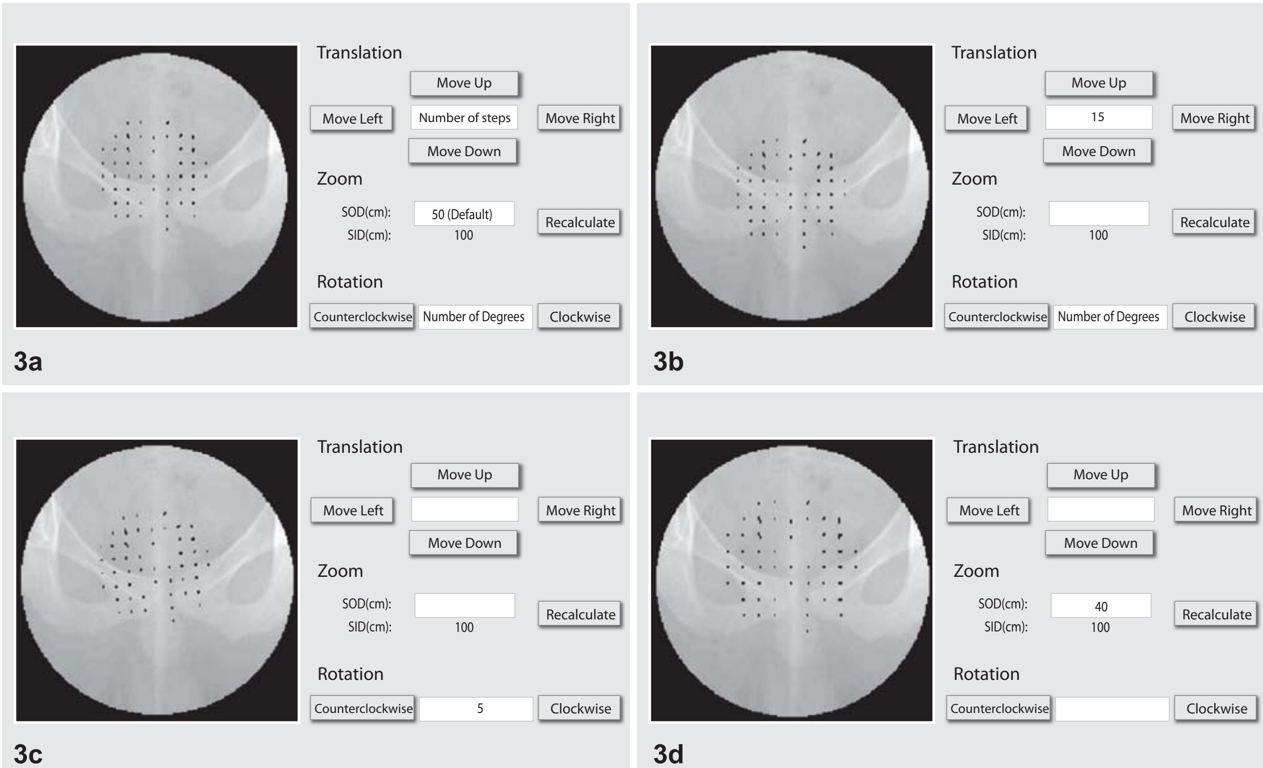

Figure 3. Distribution as displayed in the graphical user interface. The original distribution (3a) is shown as well as the resulting distribution after the original is panned (3b), rotated (3c) and zoomed (3d).

Discussion

Since fluoroscopy is ubiquitous to most surgical centers, it is a potentially useful imaging modality to optimize prostate seed brachytherapy. The purpose of this project was to create a virtual fluoroscopic image to be used as a guideline during prostate seed implantation. We have shown that this can be quickly generated for any angle although most fluoroscopic systems may not be able to have enough clearance to take images at any desired angle, especially when the patient's legs are positioned in stirrups.

Due to the fact that patient setup may be modified from that of the pre-planning volume study, the user is given the option of making changes to the distribution to reflect the different patient setup. The change in setup can also be due to the fact that the pre-implant volume study is done without full anesthesia while the implantation is performed under general anesthesia. Muscles in the pelvic region may behave differently under these two conditions such that the shape of the prostate shows differences between the day of the volume study and the day of the implantation.

The background on which the seed locations are overlaid is currently a generic image but it is possible to obtain a fluoroscopic image prior to the start of the implantation and overlay the seed information on the actual patient anatomy. This would allow the physician to use the patient's bony structure information as a guide. The SPOT-PRO system also allows for dynamic update of seed location during the seed implantation. Figure 4 shows an example where updated seed positions were used to create a distribution that is overlaid on an actual patient image as background. There is a shift observed due to swelling during the procedure which is visible when noting the location of the pubic symphysis relative to the Foley catheter. Some differences are also observed due to seeds migrating [13-15] after they are released. The virtual fluoroscopic system will not take these shifts into account.

Conclusion

The purpose of this project was to develop a platform to generate a virtual fluoroscopy image for use during prostate seed implantation. Overall, this software package provides a novel tool which may be of great value in visually determining the accuracy of an implant. The method provides the physician with imme-

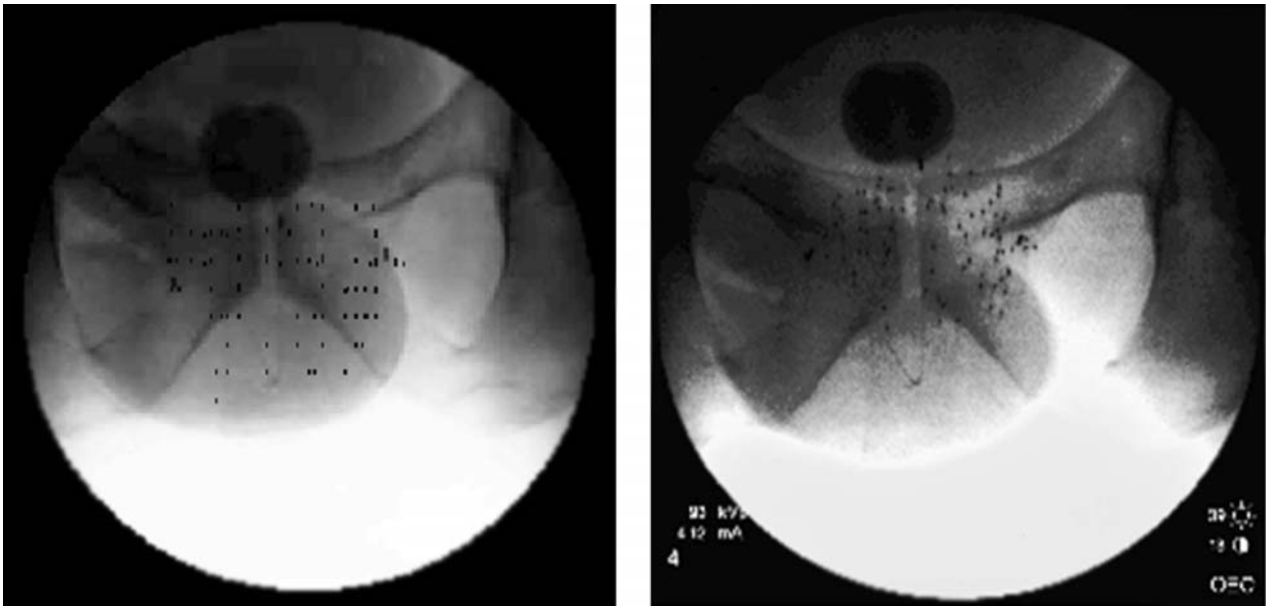

Figure 4. An image generated from updated seed positions with an actual patient image as background (left) compared with the post-implant fluoroscopic image.

diate real-time feedback so that remedial action can be taken should a large deviation be observed. This system is the first step in attempting to use the pre-plan information to aid in the seed placement. A future path of investigation may use the virtual fluoroscopy system in conjunction with an optimization routine to move each seed independently so that the virtual image matches the actual fluoroscopic image. If this can be done close to real-time, then the source positions calculated could be fed back into the planning system for immediate dosimetric feedback.

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