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Optimized needle configuration for operational seed (ONCOSEED) efficiency and deployment for prostate seed implants

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ABSTRACT

Due to anatomical changes between pre-planning and implantation, there exists a need for tools that can streamline the adjustment of needle and seed configurations in low dose rate brachytherapy for prostate cancer. Specifically, upon taking a second ultrasound on the day of treatment, the distribution of seeds and needles will differ drastically from the original plan. Clinics that employ this method must then spend time and resources to generate a workflow to manipulate the original configuration to the new configuration. ONCOSEED extracts data from VariSeed treatment plans, calculating a labor score (LScore) to optimize adjustments to needle configurations. A case study of three simulated VariSeed treatment plans was used to compare the ONCOSEED software to the manual method of generating a workflow. In the same method that was used at the authors' clinic, several assistants annotated by hand the original plan to convert it to the new plan. The time taken to do so was recorded and compared to the runtime of the software when generating a workflow for the same plan. Results showed that ONCOSEED was on average 28 times faster than generating a workflow by hand. ONCOSEED enhances the efficiency of seed replacement in LDR brachytherapy, promoting the adoption of adaptive brachytherapy practices.

Introduction

Low-dose-rate (LDR) brachytherapy using iodine-125 (I-125) sources for prostate seed implants (PSI) is a well-established treatment option for patients with localized prostate cancer [1]. Ultrasound guided prostate brachytherapy has further increased the precision of LDR prostate brachytherapy leading to better treatment outcomes [2–6]. Various seed insertion techniques are employed in PSI, including pre-loaded needle techniques with loose, linked, or stranded sources, as well as the free-seed technique using a Mick applicator [7]. Although loose seed techniques have been traditionally used and have undergone significant advancements, they may pose a higher risk for seed migration compared to other techniques [8,9]. Nevertheless, many institutions continue to employ loose seed techniques for PSI.

In institutions adhering to loose seed techniques, the treatment planning process involves an initial ultrasound-based volume study for pre-planning, followed by another ultrasound-based volume study on the day of implantation in the operating room (OR) [1,10]. Due to the time gap between the two studies and the change in patient posture, anatomical and geometrical changes can occur, necessitating modifications to the pre-plan to create an OR-plan [9].This OR-plan is created using the widely used treatment planning system VariSeed.

However, VariSeed lacks the functionality to automatically compare and highlight the differences between the pre-plan and OR-plan needle/seed configurations. As a result, the radiation oncology team must manually compare the plans, which is time-consuming and resource-intensive. Comparison of the plans is done to generate a set of steps, or workflow, that can be followed to modify the provided seeds and needles accordingly. This process of manually comparing can take an average of 30 min, leading to increased patient healthcare costs and suboptimal utilization of OR resources [11].

To address this issue, there is a pressing need for a tool that can automatically analyze the differences between pre-plan and OR-plan needle/seed configurations and provide guidance for optimal adjustments. Such a tool would streamline the workflow, reduce the workload for medical physicists, and ultimately benefit both healthcare providers

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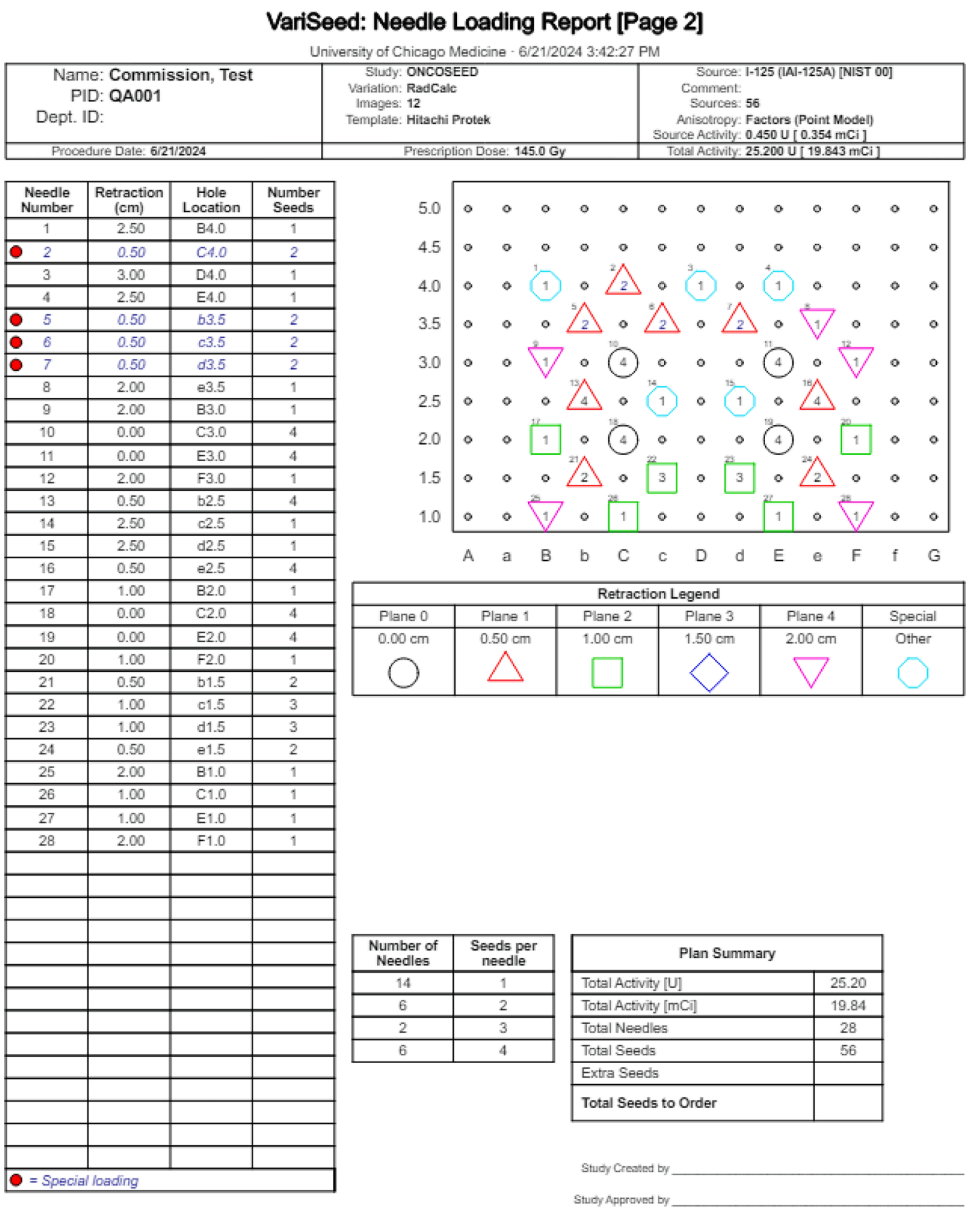
and patients by minimizing the time and effort required in the OR.

The purpose of this study is to introduce ONCOSEED (Optimized Needle Configuration for Operational Seed Efficiency and Deployment), a software tool designed to expedite and simplify the process of comparing and adjusting needle/seed configurations between pre-plans and OR-plans in PSI using loose seed techniques. By automating the analysis and providing clear guidance, ONCOSEED aims to significantly reduce the time and effort required in the OR, thereby improving the efficiency and cost-effectiveness of the PSI procedure.

Methods

Optimization seed configuration with LScore

ONCOSEED, a software developed using MATLAB (2024a, The MathWorks, Inc., Natick, MA), streamlines the process of modifying seed and spacer configurations in prostate brachytherapy plans. The software accepts a PDF file containing data from the pre-plan and OR-plan, exported from VariSeed software (Version 9.0, Varian Medical Systems, Palo Alto, CA). An example PDF treatment plan report for a simulated LDR prostate brachytherapy case is shown in Fig. 1. ONCOSEED employs Optical Character Recognition (OCR) to extract relevant information such as 'Needle Number,' 'Retraction,' 'Hole Location,' and



VariSeed: Needle Loading Report [Page 2]

University of Chicago Medicine - 6/21/2024 3:42:27 PM

Name: Commission, Test PID: QA001 Dept. ID:	Study: ONCOSEED Variation: RadCalc Images: 12 Template: Hitachi Protek	Source: I-125 (IAI-125A) [NIST 00] Comment: Sources: 56 Anisotropy: Factors (Point Model) Source Activity: 0.450 U [0.354 mCi]
Procedure Date: 6/21/2024	Prescription Dose: 145.0 Gy	Total Activity: 25.200 U [19.843 mCi]

Needle Number	Retraction (cm)	Hole Location	Number Seeds
1	2.50	B4.0	1
● 2	0.50	C4.0	2
3	3.00	D4.0	1
4	2.50	E4.0	1
● 5	0.50	b3.5	2
● 6	0.50	c3.5	2
● 7	0.50	d3.5	2
8	2.00	e3.5	1
9	2.00	B3.0	1
10	0.00	C3.0	4
11	0.00	E3.0	4
12	2.00	F3.0	1
13	0.50	b2.5	4
14	2.50	c2.5	1
15	2.50	d2.5	1
16	0.50	e2.5	4
17	1.00	B2.0	1
18	0.00	C2.0	4
19	0.00	E2.0	4
20	1.00	F2.0	1
21	0.50	b1.5	2
22	1.00	c1.5	3
23	1.00	d1.5	3
24	0.50	e1.5	2
25	2.00	B1.0	1
26	1.00	C1.0	1
27	1.00	E1.0	1
28	2.00	F1.0	1

● = Special loading

Retraction Legend					
Plane 0	Plane 1	Plane 2	Plane 3	Plane 4	Special
0.00 cm	0.50 cm	1.00 cm	1.50 cm	2.00 cm	Other

Number of Needles	Seeds per needle
14	1
6	2
2	3
6	4

Plan Summary	
Total Activity [U]	25.20
Total Activity [mCi]	19.84
Total Needles	28
Total Seeds	56
Extra Seeds	
Total Seeds to Order	

Study Created by ________________

Study Approved by ________________

VariSeed 09.00.30　4B78 D402 6D10 F712 23DE DEBD 2D

Fig. 1. Example treatment plan report from VariSeed showing the needle placement. This treatment plan was a simulation of a realistic pre-plan and OR-plan which was used to evaluate the ONCOSEED software.

'Number of Seeds' from the PDF for both plans. The OCR functionality is implemented using the MATLAB Computer Vision Toolbox, which provides a robust and efficient method for text recognition from PDF documents. The toolbox utilizes a pre-trained deep learning model for accurate character recognition, ensuring reliable extraction of the required data.

The software introduces a novel metric called the LScore, which quantifies the 'labor' required to modify the placement of seeds and spacers in the pre-plan to match the OR-plan. Each instance of removing or adding (modifying the configuration) a seed or spacer to a needle is assigned an LScore of '1′. For example, if the 13th needle in the OR-plan can be created by removing one spacer and one seed from the 5th needle in the pre-plan, the LScore for that case would be '2′. The LScore calculation begins at 0 and incrementally increases by 1 for each combination of needle placement changes that match the corresponding score. The calculation process continues until there are no more needles required for the calculation in either plan, ensuring that the OR-plan is matched.

The software generates a spreadsheet called 'work guidance' as its final output, which provides information on labor-efficient changes in needle placement. This spreadsheet serves as a valuable tool for brachytherapy practitioners, enabling them to optimize the seed and spacer configurations while minimizing the labor involved in the process described in Algorithm 1 of Fig. 2.

The ONCOSEED software offers a user-friendly interface, allowing easy input of the required PDF files and generating the 'work guidance' spreadsheet with minimal user intervention. The software's efficiency and accuracy in calculating the LScore and providing guidance on needle placement modifications have the potential to significantly improve the workflow and outcomes in prostate brachytherapy

Algorithm 1 *ONCOSEED Pre-plan and OR-plan Comparison for seed/needle configuration*

Inputs:
P_{Pre}: Pre-plan as a PDF documents.
P_{OR}: OR-plan as a PDF documents.
Outputs:
S_{work}: Work guidance spreadsheet.
for $s = 0$ to 24 **do**
  for each entry e_{OR} in P_{OR} **do**
    for each entry e_{Pre} **do**
      $D \leftarrow$ Calculate difference between $ePre$ and eOR seeds
      if e_{Pre} seeds match e_{OR} seeds **then**
        $S_{labor} \leftarrow 0$
      else if NaN in D **then**
        Continue to next iteration
      else
        Determine modification needed (removal, addition, or both of seeds)
      end if
    end for
    if S_{labor} matches current s **then**
      $D_{seeds} \leftarrow$ Calculate number of seeds difference
      Remove NaN entries from P_{Pre} and P_{OR}
    end if
  end for
  if P_{Pre} still has entries **then**
    for each remaining entry e_{Pre} in P_{Pre} **do**
      $F \leftarrow$ Determine if special, format string
      Update S_{work} with formatted F and info
    end for
  end if
  if P_{OR} still has entries **then**
    for each remaining entry e_{OR} in P_{OR} **do**
      $F \leftarrow$ Determine if special, format string
      Update S_{work} with formatted F and info
    end for
  end if
end for

Fig. 2. Algorithm describing the inputs, functions, and outputs of the ONCOSEED software.

procedures.

Evaluation

To evaluate the performance and efficiency of the ONCOSEED software, we created a set of six test files, each containing pre-plan and OR-plan data for different prostate brachytherapy cases. These test files were generated using VariSeed software and exported as PDF files. Generation with the VariSeed software was essential to ensure consistency between the case study and the clinical setting. The test plans were created to best resemble patient plans, including adhering to aspects of the guidelines for clinical practice outlined in ACR-ABS-ASTRO practice guidelines [12]. Further, each test case varies in complexity. The deviance between pre and OR plans was amplified with each test case. For instance, the first test case only moved several needles down in the coordinate plane and changed the number of seeds in some of the needles. The second test case did this but also added a needle in a new position. The final test case was the most complex, with large differences in number of needles, their locations, and their retraction values.

For each test file, we manually calculated the LScore and determined the optimal needle configuration changes required to match the OR-plan. This process was performed by experienced brachytherapy physicists and served as the ground truth for comparison. Subsequently, we processed the same test files using the ONCOSEED software and recorded the time taken by the software to generate the 'work guidance' spreadsheet. We then compared the manual calculations with the software-generated results to assess the accuracy of the ONCOSEED software.

Furthermore, we measured the time difference between the manual process and the software-assisted process for each test file. This comparison allowed us to quantify the efficiency gains achieved by using the ONCOSEED software in terms of time saved and labor reduction.

The performance evaluation results demonstrated that the ONCOSEED software accurately generated the 'work guidance' spreadsheet, with results matching the manual calculations in all six test cases. Moreover, the software significantly reduced the time required to determine the optimal needle configuration changes, with an average time savings of [insert time difference] compared to the manual process. These findings validate the effectiveness and efficiency of the ONCOSEED software in optimizing needle configurations for prostate brachytherapy, highlighting its potential to streamline the treatment planning process and improve clinical workflows.

Comparison with standard method

To demonstrate the efficiency of the ONCOSEED software, we compared the time taken to generate the 'work guidance' spreadsheet using the software with the time taken to annotate and correct the paper OR-plan manually by human readers. We used the time efficiency formula to systematically evaluate the efficiency of the ONCOSEED software.

$$Efficiency = \frac{(standardlaborhours)}{(timeworked)} \times 100\% \quad (1)$$

In this study, we used the time taken manually as the standard. The "time worked" variable, then, is the time the ONCOSEED software took. The results are summarized in Table 1.

Results

Results of the performance on three simulated treatment plans indicate a significant reduction in time needed to compare pre- and OR-plans. The average time required for ONCOSEED to prepare the plan comparison was 14.7 s, while the average manual time was 410 s. The ONCOSEED software was, on average, 28 times more efficient than the human readers. The results for each simulated case are presented in Table 1.

Discussion

Based on our results, we demonstrate that the ONCOSEED software method is more efficient in optimizing seed replacement from the new OR-plan when compared with a pre-operational plan. However, several considerations must be made in the implementation and clinical use of the ONCOSEED software. Firstly, the sample data used in our case study were simulated LDR prostate brachytherapy treatment plans, and may not represent all variations in seed placement plans employed in the clinical setting. However, since the needle and source positions are discrete and fixed within the VariSeed treatment planning system, treatment plans will not vary so significantly that ONCOSEED cannot process the changes. A simplification of treatment plans only expedites the manual process when lab aids read the sheet. However, it is possible to imagine that the processing time for the ONCOSEED method varies far less with changes in treatment complexity than the time needed for a human observer to evaluate the changes. Therefore, the efficiency calculated in our study underestimates the true potential and ability of ONCOSEED to greatly impact the clinical setting.

The necessity of this software in the clinical practice is important to consider. For instance, dynamic dose calculation is being favored for its improved accuracy [13]. However, it is important to note that not all clinics employ the latest methods of radiation oncology. For whatever reason a clinic has, they may choose to continue their existing practices. Such is the case of the clinics observed that were the inspiration for this software. ONCOSEED was developed to aid those who continue to use the pre-planning method and then doing a second volume study. One may also ask why a second volume study is necessary at all. This, like using pre-planning at all, is up to the clinic. Due to anatomical and geometric changes between pre-planning and the treatment date, a new plan would be the most accurate and of highest quality in providing care.

Furthermore, although many clinics are starting to adopt adaptive therapy practices such as conducting a second volume study on the day of treatment, not all clinics will have a second ultrasound to generate an OR-plan. Since a second volume study, conducted just prior to giving treatment, will increase the accuracy of the treatment plan, we believe that the ONCOSEED software will further promote the adoption of this practice in the clinic. What deters physicians from the adaptive approach is the tedious nature of comparing the pre-OR plan to the OR plan as well as swapping needles and seeds in the VariSeed system. However, with ONCOSEED, we greatly reduce the time needed to compare plans and reconfigure the sources.

Future research should focus on validating the ONCOSEED software with patient treatment plans in a clinical setting. Additionally, a multi-institutional review of adaptive LDR brachytherapy clinics can identify common practices which may impact the software's performance. It would also be useful to compare the current time burden of comparing treatment plans between different institutions to further evaluate the software's increased efficiency.

Lastly, there is the concern of the implications ONCOSEED has on dose calculations. It is important to note that the ONCOSEED system is not a substitute for or a novel treatment planning system itself. As mentioned earlier, the pre-plan and OR-plan are both made in the

Table 1
Case study results for the three simulated LDR prostate brachytherapy cases.

Case	Manual Time (sec)	ONCOSEED Time (sec)	Efficiency (%)
Case 1	357.0	8.1	4,414.8 %
Case 2	415.0	14.5	2,862.1 %
Case 3	460.0	21.6	2,131.0 %
Avg	410.0	14.7	2,795.2 %

VariSeed TPS. ONCOSEED is simply a tool to read these plans and generate the most optimal workflow for treatment.

Conclusion

ONCOSEED is an example of a novel software tool which, when fully implemented into the clinical brachytherapy practice, increases the accuracy and efficiency of the previously labor-intensive process of comparing pre-plans with re-plans generated in the OR before implantation. Although the benefit may seem modest, decreasing the time required to compare plans is essential to building a truly adaptive brachytherapy workflow. The benefits that may result from adaptive LDR prostate brachytherapy include more accurate dose delivery, ultimately improving treatment outcomes. Software tools such as ONCOSEED remain an important part of the brachytherapy practice and should be considered when designing innovative treatment protocols.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] Davis BJ, Horwitz EM, Lee WR, Crook JM, Stock RG, Merrick GS, American Brachytherapy Society. American Brachytherapy Society consensus guidelines for transrectal ultrasound-guided permanent prostate brachytherapy. Brachytherapy 2012;11(1):6–19.

[2] Benoit RM, Naslund MJ, Cohen JK. A comparison of complications between ultrasound-guided prostate brachytherapy and open prostate brachytherapy. Int J Radiat Oncol Biol Phys 2000;47(4):909–13.

[3] Beyer DC, Priestley JB. Biochemical disease-free survival following 125I prostate implantation. Int J Radiat Oncol Biol Phys 1997;37:559–63.

[4] Holm HH, Juul N, Pedersen JF, et al. Transperineal I-125 seed implantation in prostatic cancer guided by transrectal ultrasonography. J Urol 1983;130:283–6.

[5] Ragde H, Blasko JC, Grimm PD, et al. Interstitial iodine-125 radiation without adjuvant therapy in the treatment of clinically localized prostate carcinoma. Cancer 1997;80:442–53.

[6] Wallner K, Roy J, Harrison L. Tumor control and morbidity following transperineal iodine 125 implantation for stage T1/T2 prostatic carcinoma. J Clin Oncol 1996;14:449–53.

[7] Zauls AJ, Ashenafi MS, Onicescu G, Clarke HS, Marshall DT, Sathiaseelan V. Comparison of intraoperatively built custom linked seeds versus loose seed gun applicator technique using real-time intraoperative planning for permanent prostate brachytherapy. Int J Radiat Oncol Biol Phys 2011;81(4):1010–6.

[8] Tapen EM, Blasko JC, Grimm PD, Ragde H, Luse R, Clifford S, et al. Reduction of radioactive seed embolization to the lung following prostate brachytherapy. Int J Radiat Oncol Biol Phys 1998;42(5):1063–7.

[9] Seifi A, Walter A, Kader AH, Alizadeh M, Schreiber S, Rolf S, et al. The impact of frog-leg position on the geometry of the prostate and surrounding structures assessed with pre-implant MRI–a prospective study. J Contemporary Brachytherapy 2015;7(3):198.

[10] Rubens DJ, et al. Image-Guided Brachytherapy for Prostate Cancer. Radiologic Clinics 2006;44(5):735–48.

[11] Shah C, Lanni Jr TB, Ghilezan MI, Gustafson GS, Marvin KS, Ye H, et al. Brachytherapy provides comparable outcomes and improved cost-effectiveness in the treatment of low/intermediate prostate cancer. Brachytherapy 2012;11(6):441–5.

[12] Harkenrider MM, Albuquerque K, Brown D, Kamrava M, King M, Mourtada F, et al. ACR-ABS-ASTRO practice parameter for the performance of radionuclide-based high-dose-rate brachytherapy. Brachytherapy 2021;20(6):1071–82.

[13] Kuo N, Dehghan E, Deguet A, Mian OY, Le Y, Burdette EC, et al. An image-guidance system for dynamic dose calculation in prostate brachytherapy using ultrasound and fluoroscopy. Med Phys 2014 Sep;41(9):091712. https://doi.org/10.1118/1.4893761. PMID: 25186387; PMCID: PMC4149691.