Image analysis-based quality assurance of ^{125}I seed plaque assembly for ocular brachytherapy

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Background

Ocular brachytherapy is a radiation therapy for ocular melanomas and retinoblastomas.[1] It involves the deposition of radiation into eye tumors using sealed sources arranged on gold plaques. At Thomas Jefferson University, ^{125}I seed sources are arranged in custom layouts on the plaques to optimally target the tumor volume.

For plaque construction, the medical physicist glues seeds onto the plaque while visually following a printout photo of a simulated treatment plan. For quality assurance (QA), a second medical physicist checks that the final seed placement visually matches the plan. It is unclear if seed displacement and orientation is accurately assessed due to the dependance on visual assessment.

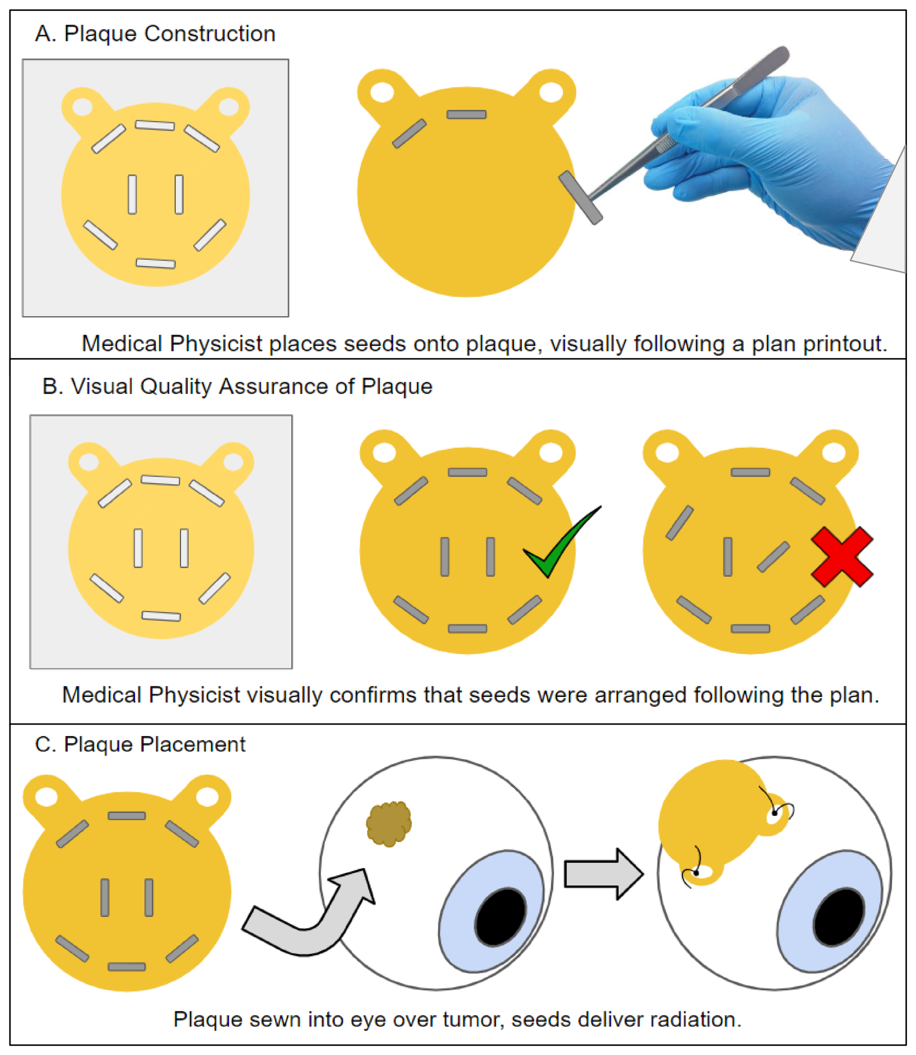

Fig 1. Steps of plaque assembly, quality assurance (QA), and surgical plaque placement for ocular brachytherapy.

Purpose

The purpose of this project was to design and demonstrate the utility of an image analysis QA program to compare actual seed placement on the plaque with the seed arrangement of the treatment plan, providing both qualitative and quantitative feedback.

Methods

1. **Plaque Preparation:** Model plaques were 3D printed and painted gold to mimic clinical plaques. Non-radioactive ^{125}I seeds were glued onto model plaques following two clinically relevant treatment plans. Five clinical plaques used for treatments were also analyzed.
2. **Plaque Imaging:** Plaques were photographed using a DSLR camera mounted on a vertical stand. A 3D printed plaque holder was used to hold the plaques in reproducible positions. Images were processed in Lightroom Classic.
3. **Image Analysis:** An image analysis QA program was written in MATLAB to compare actual seed placement with the treatment plan. The QA program provided analyses of each seed's distance and orientation displacement from the intended seed position.
4. **Error Determination:** A Mitutoyo Standard Scale (172-116, 50mm) was imaged alongside five ^{125}I seeds. The images were processed and analyzed with the QA program, and the final scaling error was calculated.

Model Plaque Results

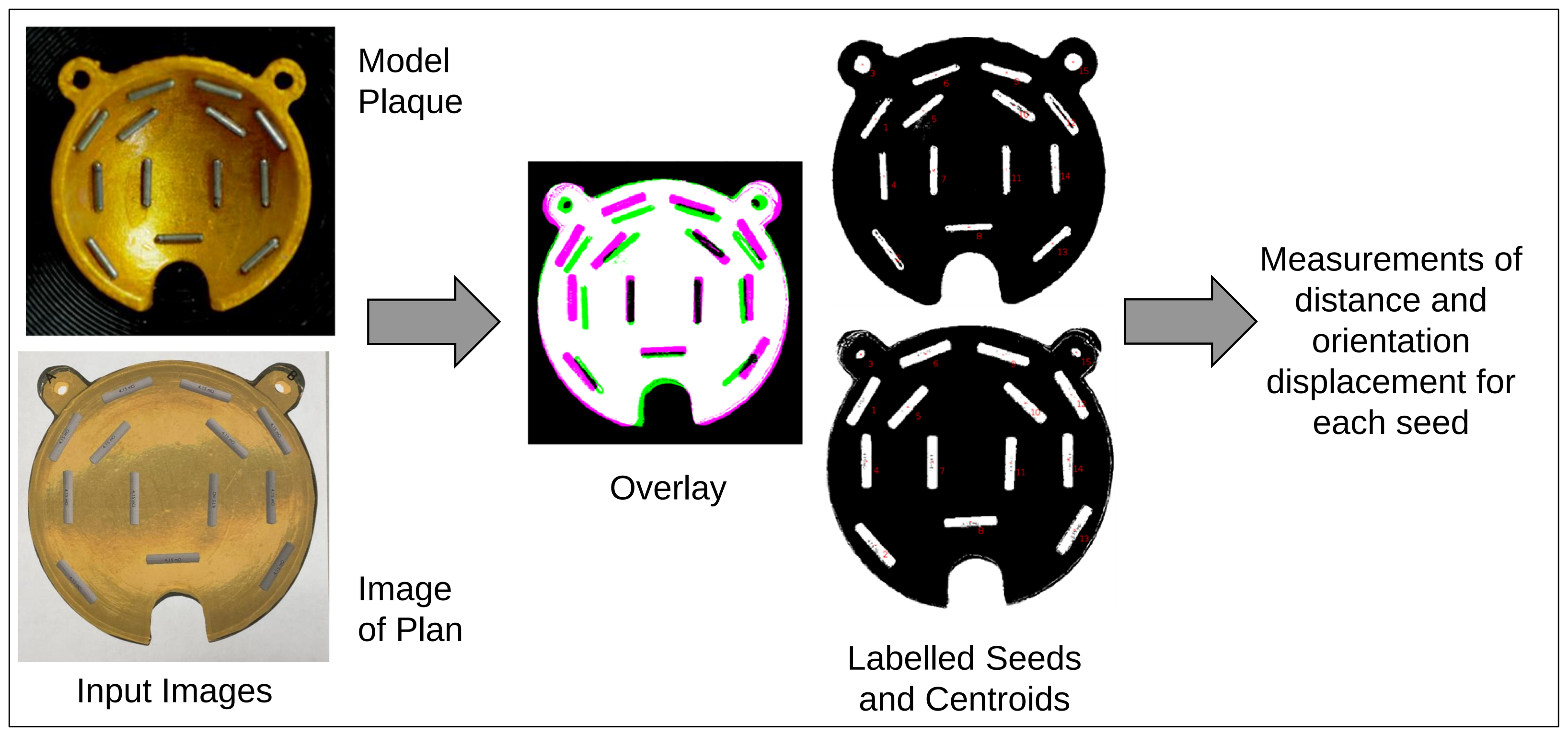

Fig 2. Flowchart of inputs and outputs for the MATLAB QA program.

			Seed Displacement (mm)		Seed Orientation Difference (degrees)	
Plaque Identifier	Medical Physicist	Treatment Plan	Mean	SD	Mean	SD
M7	Physicist 1	22N, 13 seeds	1.672	0.597	6.948	7.955
M8	Physicist 1	22N, 13 seeds	1.481	0.680	5.267	4.498
M9	Physicist 1	22N, 13 seeds	1.529	0.712	5.525	4.113
M10	Physicist 1	15R, 4 seeds	1.318	0.445	7.333	4.974
M11	Physicist 1	15R, 4 seeds	1.139	0.320	8.326	2.727
M12	Physicist 1	15R, 4 seeds	1.889	0.494	4.408	4.929
M13	Physicist 2	15R, 4 seeds	1.080	0.207	5.382	5.542
M14	Physicist 2	15R, 4 seeds	0.945	0.189	5.121	3.490
M15	Physicist 2	15R, 4 seeds	1.322	0.307	2.005	1.040
M16	Physicist 2	22N, 13 seeds	0.990	0.486	4.644	4.408
M17	Physicist 2	22N, 13 seeds	1.030	0.373	4.875	4.168
M18	Physicist 2	22N, 13 seeds	1.204	0.765	4.034	3.913
	All Plaques	102 seeds	1.309	0.605	5.266	4.768

Table 1. Seed Displacement (mm) and Orientation Difference (degrees) averages for 22 Notch and 15 Round Plaque Models constructed by two Medical Physicists following the same treatment plans.

Clinical Plaque Results

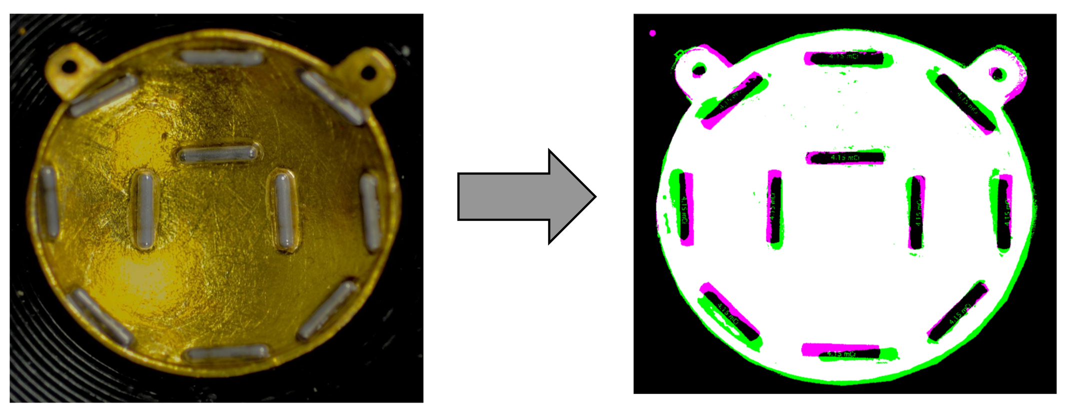

Fig 3. Example QA program use with clinical plaques. Processed image of P3 plaque and final QA program generated overlay image of plaque and treatment plan.

			Seed Displacement (mm)		Seed Orientation Difference (degrees)	
Plaque Identifier	Plaque Type	Seeds	Mean	SD	Mean	SD
P1	18mm Notch	9	0.981	0.389	3.347	2.310
P2	18mm Round	12	0.959	0.320	4.388	2.330
P3	20mm Round	11	0.454	0.353	5.625	4.380
P4	18mm Deep Notch	11	0.616	0.371	3.143	2.510
P5	15mm Round	8	0.899	0.497	5.681	2.244
	All Plaques	51	0.771	0.425	4.405	2.998

Table 2. Seed Displacement (mm) and Orientation Difference (degrees) averages for five clinical plaques as measured by the QA program.

Software Validation

Seed Length (pixels)	mm/pixel Ratio	1 mm Calculated Length (mm)	Percent Error (%)
275.46	0.01693	1.0158	1.58
271.03	0.01721	1.0326	3.26
276.36	0.01688	1.0128	1.28
270.05	0.01727	1.0362	3.62
274.80	0.01697	1.0182	1.82
		Average Percent Error	2.312

Table 3. Percent error calculations for scaling based on seed length, using an average seed length of 4.664 mm (measured from seed samples).

Discussion

The image analysis program was able to detect sub-millimeter scale differences in seed position with 2.31% error (Table 3).

The average seed displacement on the model plaques was 1.309 mm (SD = 0.605), with a maximum displacement of 2.95 mm (Table 1). The average orientation difference on the model plaques was 5.266 degrees (SD = 4.768), with a maximum orientation difference of 27.95 degrees (Table 1).

The average seed displacement of the patient plaques was 0.771 mm (SD = 0.425), with a maximum displacement of 1.62 mm (Table 2). The average orientation difference on the patient plaques was 4.405 degrees (SD = 2.998), with a maximum difference of 17.24 degrees (Table 2).

Conclusion

This research demonstrated accurate characterization of seed placement for both 3D printed model plaques and clinical plaques with radioactive seeds. In future work, we will investigate how seed position data can be used to calculate an updated dosimetry.

Detecting misplaced seeds is important because a miniscule shift can result in higher doses to critical structures such as the fovea and optic nerve, placing the patient at a higher risk of permanent vision loss. Additionally, a significant displacement in seed position could result in insufficient dose to the tumor volume, increasing the risk of tumor recurrence.

Thus, detecting and correcting misplaced seeds is critical for improving patient outcomes. If implemented, the developed QA program can increase the accuracy of dose delivery at facilities using custom plaques for ocular brachytherapy.

References

1. ABS – OOTF Committee. The American Brachytherapy Society consensus guidelines for plaque brachytherapy of uveal melanoma and retinoblastoma. Brachytherapy. 2014;13(1):1-14. doi:10.1016/j.brachy.2013.11.008