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Utilization of Neurosurgical Biopsy Navigation System for Permanent Ra-224 Intracranial Implant in Phantom and Patient Studies

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ABSTRACT

Purpose: To evaluate the feasibility, geometric accuracy, and dosimetric performance of stereotactic implantation of Diffusing Alpha-emitters Radiation Therapy (Alpha-DaRT) sources for intracranial tumors using a neurosurgical navigation system.

Methods: Three anthropomorphic phantom studies and the first treated clinical patient underwent MRI-guided treatment planning, stereotactic implantation using a custom radial applicator, and post-implant CT-based dosimetric evaluation. Implant positional accuracy and target coverage were compared with the pre-operative treatment plan.

Results: Phantom implants demonstrated radial deviations of 0.5-2.0mm and depth deviations of 0.6-1.5mm, resulting in target coverage ranging from 86.7-91.8% compared with planned coverage of 94.0-95.3%. The first clinical implantation achieved 95.4% target coverage versus 97.7% planned.

Conclusions: Stereotactic Alpha-DaRT implantation using a commercially available neurosurgical navigation platform is technically feasible, reproducible, and capable of achieving clinically acceptable dosimetric coverage, supporting further clinical evaluation for intracranial malignancy.

INTRODUCTION

High-grade gliomas remain among the most difficult malignancies to treat because of their aggressive biology and high rates of local recurrence, often within previously irradiated tissue. Diffusing Alpha-emitters Radiation Therapy (Alpha-DaRT) are a novel brachytherapy modality capable of delivering highly focused radiation while sparing surrounding tissue.

Alpha-DaRT sources consist of titanium seeds coated with radium-224 that continuously release short-lived alpha-emitting daughter isotopes capable of diffusing several millimeters into surrounding tissue. The resulting high-LET radiation produces dense DNA double-strand breaks making the technique an attractive treatment for recurrent glioblastoma.

Successful intracranial application of Alpha-DaRT requires highly accurate stereotactic implantation. A neurosurgical navigation system, Medtronic StealthStation, traditionally used for stereotactic brain biopsies, was integrated with a custom-designed radial Alpha-DaRT applicator to enable precise source implantation. This study evaluated implantation accuracy, reproducibility, and dosimetric coverage using an anthropomorphic phantom to demonstrate initial clinical feasibility.

METHODS AND MATERIALS

An anthropomorphic intracranial phantom was constructed to simulate human brain anatomy and density. Three intracranial lesions representing clinically relevant recurrent glioblastoma geometries and locations derived from actual patient imaging were contoured on CT and MRI datasets using MIM Symphony.

Treatment planning MRI datasets were imported into the Medtronic StealthStation surgical navigation system. The neurosurgeon selected stereotactic entry points and target coordinates based on optimal biopsy trajectories while avoiding critical structures. These coordinates were transferred to the Alpha-DaRT planning workflow within MIM Symphony, where individualized source configurations were optimized for target coverage

Source length and number were selected according to lesion dimensions using predefined implantation configurations of Alpha-DaRT sources with lengths of 10 and 20 mm. Sources were implanted using a custom-designed radial applicator compatible with a standard stereotactic biopsy needles. The applicator deployed seven sources radially in umbrella-like layers. Following placement of each layer, the needle was withdrawn to the next planned depth, allowing sequential deployment throughout the target volume.

RESULTS

The phantom studies required implantation of 27, 42, and 56 Alpha-DaRT sources for the three lesion configurations.

Detailed geometric analysis demonstrated angular deviations below 3°, and radial deviations averaging approximately 1.2 mm.

Maximum radial deviations from the planned positions were 0.5, 1.3, and 2.0 mm, while maximum depth deviations were 0.6, 1.0, and 1.5 mm, respectively. Planned target coverage ranged from 94.0% to 95.3%, whereas post-implant coverage measured 86.7%, 91.8%, and 90.5%, demonstrating excellent agreement despite minor implantation deviations.

The smallest lesion exhibited the greatest sensitivity to small positional deviations, explaining its slightly reduced dosimetric coverage compared with larger targets.

The first clinical patient underwent implantation of 21 Alpha-DaRT sources. Treatment planning predicted 97.7% clinical target volume coverage. Post-implant CT demonstrated 95.4% target coverage, confirming successful translation of the phantom workflow into the clinical environment with excellent agreement between planned and delivered dose distributions.

DISCUSSION

This work demonstrates that stereotactic Alpha-DaRT implantation can be performed with high geometric precision using a commercially available neurosurgical navigation platform. Across phantom studies, radial and depth deviations remained within approximately 2 mm while maintaining target coverage exceeding 90% in most cases. The initial clinical experience further confirmed that these techniques can be translated safely into patient treatment while maintaining excellent dosimetric agreement with pre-operative planning.

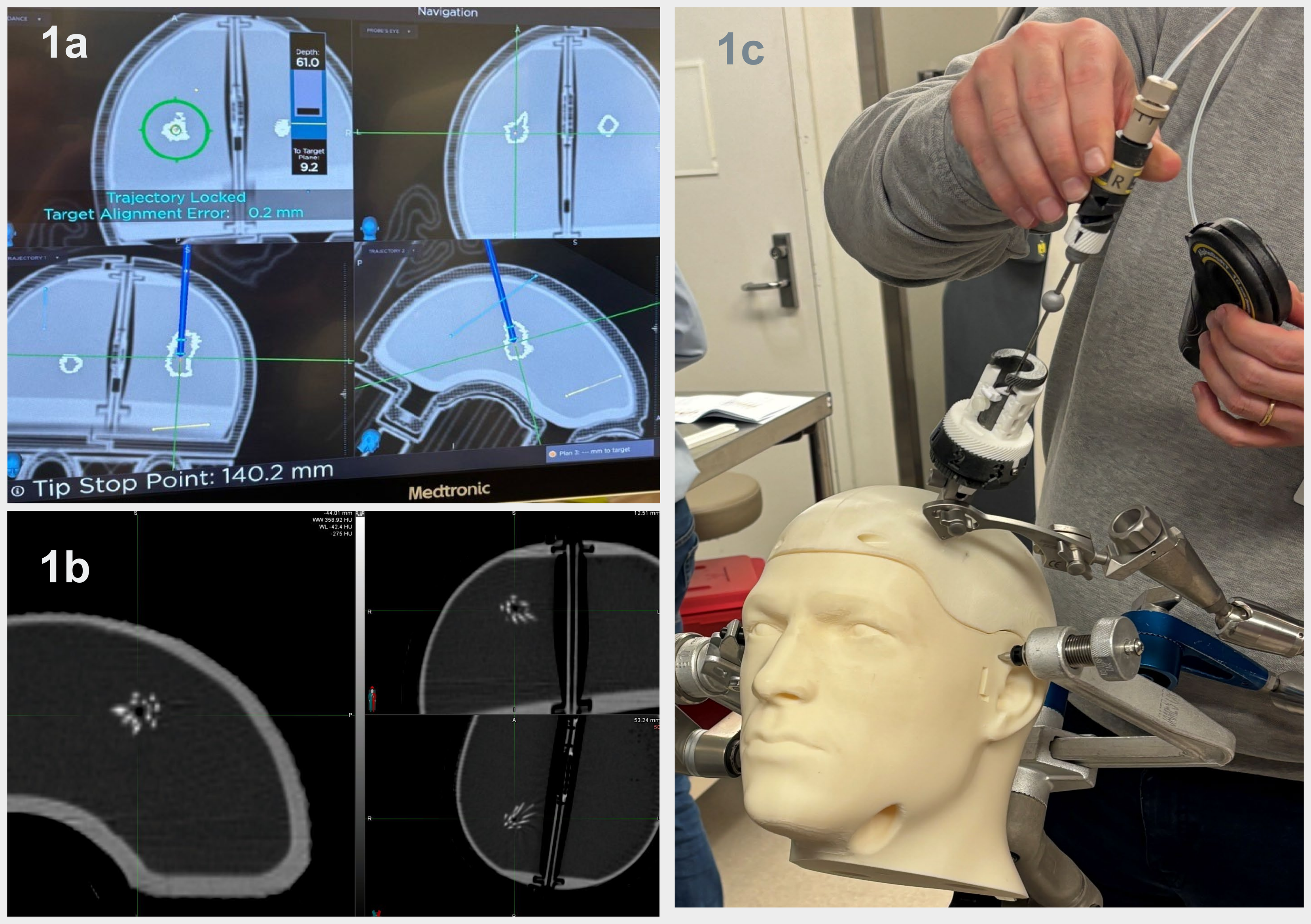
The combination of MRI-based planning, Medtronic stereotactic navigation, and the dedicated radial applicator enabled reproducible implantation across multiple lesion sizes. Although small geometric deviations modestly reduced target coverage, particularly for the smallest lesions, clinically acceptable coverage was maintained. The first patient results demonstrated nearly identical target coverage between planned and delivered treatments, providing encouraging early evidence of clinical feasibility.

CONCLUSIONS

Alpha-DaRT implantation using the Medtronic StealthStation surgical navigation system and a custom radial applicator can be performed with high spatial accuracy, reproducibility, and favorable dosimetric characteristics.

Phantom studies demonstrated sub-2mm implantation accuracy while maintaining target coverage near planned values. These findings establish the technical feasibility of stereotactic intracranial Alpha-DaRT implantation and support continued prospective clinical evaluation as a novel treatment strategy for intracranial malignancies.

Initial trial patients have shown similar accuracy and ability to maintain compare prescription coverage.



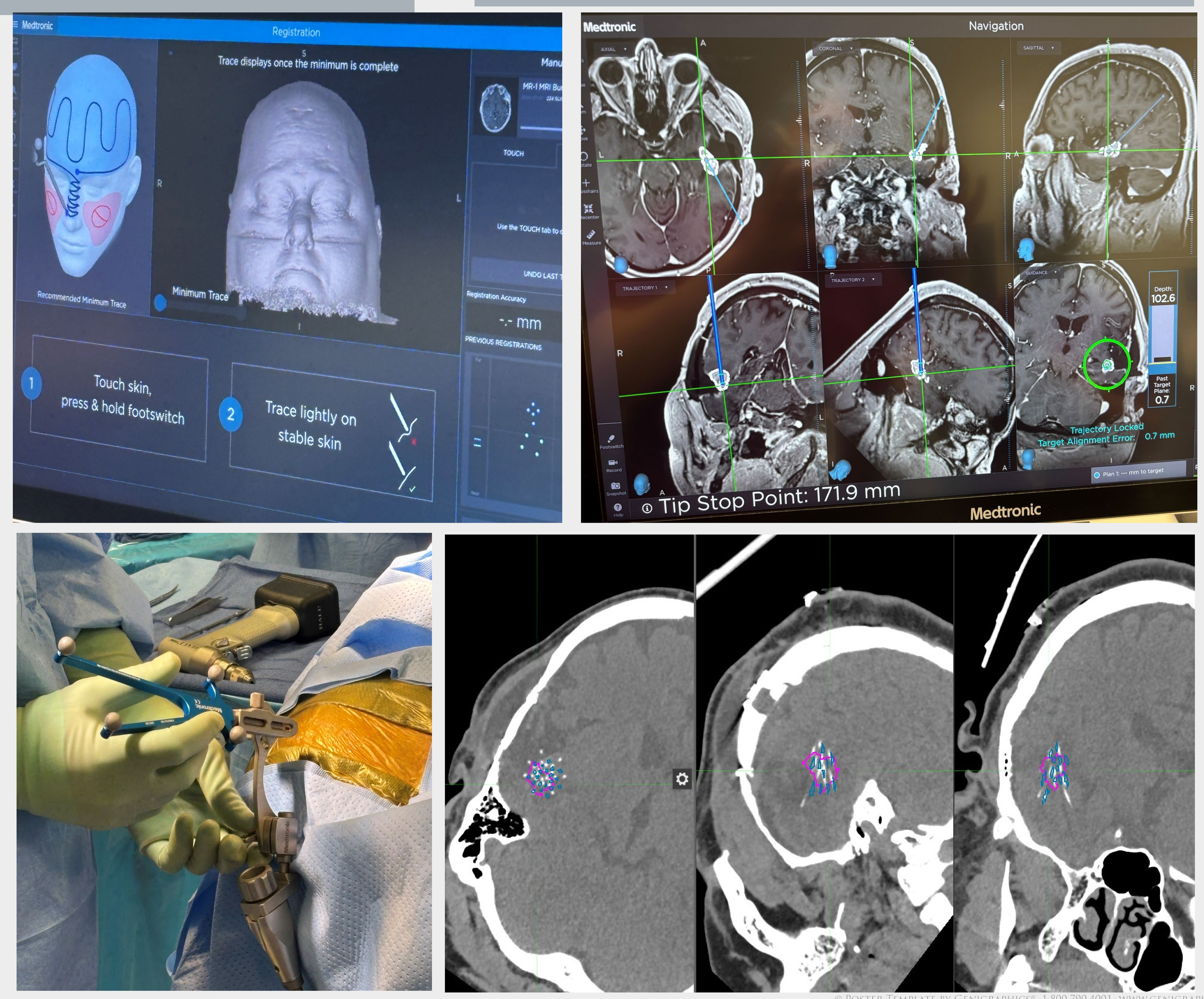


Figure 1 (Above): Anthropomorphic intracranial phantom study (a) Navigation system biopsy needle positioning, (b) Phantom implant CT, (c) Modified biopsy needle for implantation setup
Figure 2 (Right): Trial patient implant (a) Navigation surface guidance (b) Navigation biopsy needle placement (c) Trajectory alignment with infrared makers (d) Post implant CT, planned seeds in blue

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