Digital Uniform Nesting Enclosure (DUNE) for Radiation Therapy in Early-stage Dupuytren's Disease

ABSTRACT

Purpose: Dupuytren's contracture is a progressive fibroproliferative disorder affecting the palmar fascia. While radiation therapy (RT) shows promise for early-stage disease, precise hand positioning during treatment is crucial for optimal outcomes. This study introduces the DUNE (Dupuytren's Unique Nesting Enclosure) box, a novel 3D-printed patient-specific hand restraint, aimed at optimizing treatment delivery through improved positioning accuracy and reproducibility.

Methods and Materials: We first quantitatively evaluated the impact of hand positioning on dose distribution using 3D-printed blocks with varying finger flexion angles (0°, 10°, 20°, 30°, 45°). Based on these findings, a hand phantom was digitally scanned by using a 3D hand-held scanner and used to create a custom DUNE box. The box's effectiveness was evaluated through comprehensive dosimetric analysis using radiochromic film measurements, setup reproducibility assessment, and workflow integration studies. Systematic comparisons were made between the DUNE box and conventional tape immobilization methods.

Results: Dosimetric analysis of the angled blocks showed optimal dose distribution at 0° flexion, with conformity index (CI) of 0.95 and homogeneity index (HI) of 1.05, progressively worsening as angles increased. The DUNE box improved dose distribution uniformity by 11.5% ± 2.0% compared to conventional methods. Setup reproducibility improved significantly, with mean positioning displacement reduced from 3.8 ± 0.7 mm to 1.2 ± 0.3 mm ($p < 0.001$). While initial DUNE box setup time was longer (5.3 ± 0.8 vs 3.2 ± 0.5 minutes, $p < 0.05$), it showed a 28% decrease over ten trials, indicating a rapid learning curve.

Conclusion: The DUNE box demonstrates significant improvements in setup reproducibility and dose distribution uniformity for radiation therapy in early-stage Dupuytren's contracture. While requiring additional initial setup time and resource investment for 3D printing (approx. 3 hours), its superior dosimetric advantages and improved positioning accuracy suggest potential for enhancing treatment outcomes. Further clinical validation through prospective trials is needed to assess long-term clinical benefits and cost-effectiveness.

KEYWORDS: Dupuytren's contracture, Radiation therapy, 3D printing, 3D scanning, DUNE