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Implementation of an Automated Field-in-Field Optimization Algorithm within Eclipse Scripting API Using K-Means Clustering and Linear Programming

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ABSTRACT

Purpose: Field-in-field (FIF) tangential 3D conformal radiotherapy (3D-CRT) remains a widely used planning approach for whole-breast irradiation and is recommended in professional guidance as an appropriate initial technique when clinically suitable. However, manual FIF creation is iterative and time intensive. We developed an Eclipse v18 scripting workflow that generates FIF subfields from an optimized fluence solution and refines monitor units (MUs) using a convex linear program that balances hotspot suppression and target coverage. We compared plan quality against a commercial automation solution (EZFluence v2.4.4).

Methods: Twenty retrospectively selected whole-breast patients (10 left, 10 right) treated supine were replanned with the proposed script and with EZFluence. Prescriptions ranged 40.05–50 Gy in 15–25 fractions. All plans used identical open-field geometry, three subfields per tangent, and GPU-based optimization and dose calculation. For comparison, plans were evaluated on the EZFluence-generated evaluation target (PTV_EVAL_EZ) and normalized to matched maximum doses of 110% and 106%. Metrics included target coverage and hotspot volumes (V105%, V107%) and mean doses to heart and lungs.

Results: For 110% normalization, mean V100% was similar between EZFluence and script plans (90.10% vs 90.33%), while V105% and V107% were lower with our script (36.27% vs 47.67% and 9.62% vs 19.14%). For 106% normalization, V95% was similar (94.62% vs 94.87%) and V105% was slightly reduced (0.42% vs 0.73%). Mean heart and lung doses were similar between methods at both normalization levels. End-to-end planning time was a few minutes with GPU enabled.

Conclusion: An Eclipse-native automated FIF workflow with Conditional value at risk (CVaR)-based MU refinement reduced hotspot volumes compared with EZFluence at matched maximum dose, with similar target coverage and organ-at-risk sparing.

INTRODUCTION

Forward-planned field-in-field (FIF) tangents remain a standard approach because they improve dose homogeneity and reduce hotspots relative to open tangents while preserving simple, robust delivery. Manual FIF planning is inherently iterative, time consuming and planner dependent, especially for challenging breast geometries.

These workflow limitations have motivated automation of tangential breast planning. EZFluence is a commonly used commercial option in Eclipse that automates FIF/electronic-compensator–style planning and has been reported to reduce planning time with clinically acceptable dosimetry.

Although commercial automation solutions are generally effective, their implementations are proprietary and black box. We therefore developed an Eclipse v18 scripting workflow that performs Eclipse-native FIF generation to reduce V105%/V107% at matched maximum dose while maintaining coverage and OAR sparing.

METHODS AND MATERIALS

Target definition for optimization

We generated an optimization target using the 90% isodose surface derived from the initial open-field dose.

Fluence optimization in Eclipse

A new plan was created with identical tangent beams but with the MLC removed to enable fluence optimization. Fluence smoothing factors were set to 60 in leaf-motion directions and perpendicular directions. Optimization objectives were selected to enforce homogeneity by applying a lower constraint to push V95% to 97.5% (weight 100) and an upper constraint limiting maximum dose to 90% of the prescription (weight 60), with the normal tissue objective disabled.

Fluence-to-aperture conversion

Optimized fluence maps were converted into deliverable subfields using 1D k-means clustering over fluence pixel intensities. The open tangent fields remained unchanged, and three subfields per tangent were generated for all plans.

MU refinement via CVaR-based convex optimization

After dose calculation with the open fields and subfields, MUs were refined without requiring repeated dose recalculation by solving a linear program over a sampled set of PTV voxels. We randomly sampled 3000 points in the target and queried dose contributions from Eclipse for each field to form a dose deposition matrix.

We minimized a composite hotspot objective consisting of the max dose and an upper-tail CVaR term at a 20% volume threshold. To preserve coverage, we enforced a cold-tail constraint using lower CVaR at a 10% threshold larger than prescription dose.

The linear program was solved using the ALGLIB numerical library. The sampling and optimization were repeated 10–30 times, and the best solution (by dosimetry metrics) was selected.

EZFluence (v2.4.4) plans were generated retrospectively using the same open-field geometry and prescription. The default EZFluence plan, which balances coverage and overdose, was used for comparison with three subfields.

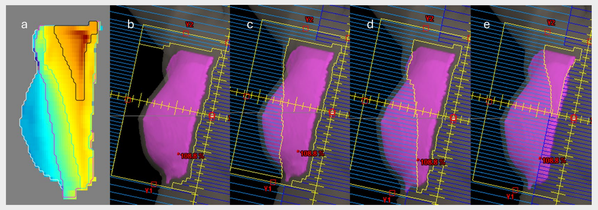

Figure 1.example of a typical fluence map with MLC contours overlayed on top (a), open field (b) and subfields 1-3 (c-e).

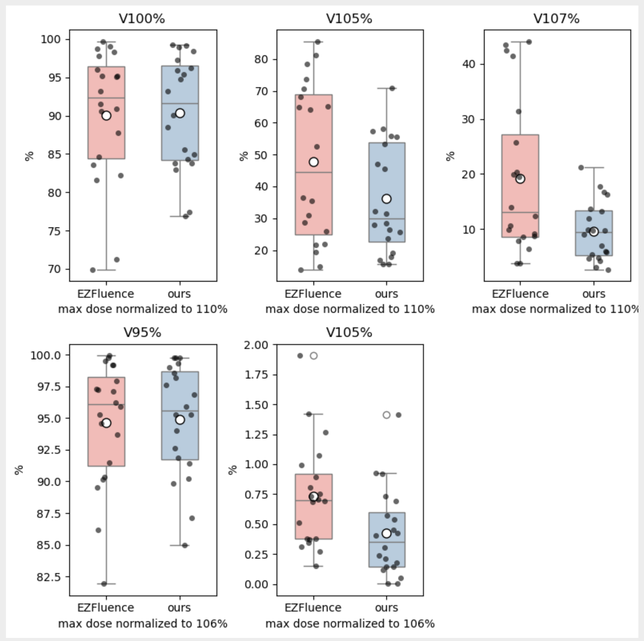

Figure 2. Box plots for the comparisons of dosimetry metrics. White circles represent the mean value.

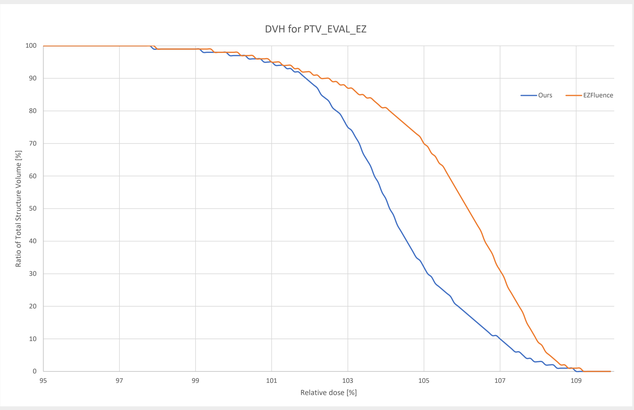

Figure 3. DVH comparison.

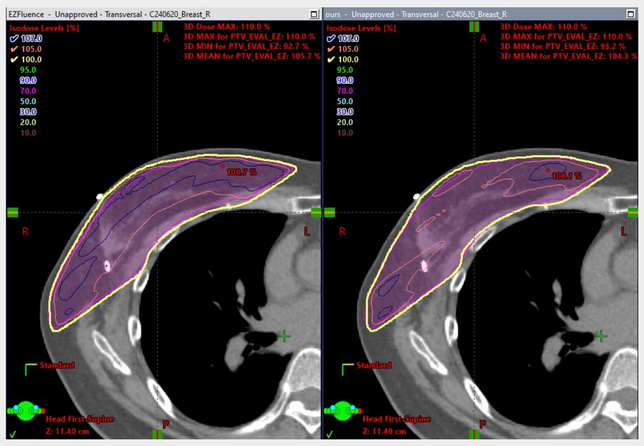

Figure 4. Isodose comparison for EZFluence (left) and our script (right) for 105% (pink) and 107% (blue).

RESULTS

With GPU acceleration, the scripted workflow completed end-to-end FIF generation in a few minutes. Fig. 1 shows an example of a fluence map with contours overlayed on top, open field and all subfields.

Normalization to 110% maximum dose

Target coverage was similar between methods: mean V100% was 90.10% for EZFluence and 90.33% for the script (p=0.71) (fig 2). Hotspot volumes were reduced with our script: mean V105% was 47.67% (EZFluence) vs 36.27% (ours) (p<0.01), and mean V107% was 19.14% (EZFluence) vs 9.62% (ours) (p<0.01) (fig 2).

Mean heart and lung doses were similar: heart mean dose was 0.0160% (EZFluence) vs 0.0158% (ours)(p<0.01), and lung mean dose was 0.0700% (EZFluence) vs 0.0687% (ours)(p<0.01).

Normalization to 106% maximum dose

Target coverage was again similar: mean V95% was 94.62% for EZFluence vs 94.87% for our script (p=0.25) (fig2). Mean V105% was reduced from 0.73% (EZFluence) to 0.42% (ours)(p=0.023) (fig2).

Mean heart and lung doses remain comparable: heart mean dose 0.0154% (EZFluence) vs 0.0153% (ours)(p<0.01); lung mean dose 0.0674% (EZFluence) vs 0.0662% (ours)(p<0.01).

Representative DVH demonstrated similar coverage with reduced hot-tail dose for the scripted plans (fig3). The Isodose plot shows a reduction in the V107% and V105% for one typical case (fig4).

DISCUSSION

Two features likely contributed to the observed hotspot reductions. First, all optimization and dose computation were performed within Eclipse using the same dose engine used for final evaluation, reducing mismatch between an intermediate optimized representation and the delivered aperture set. Second, the final MU optimization used a convex formulation that directly suppresses both peak dose and the hot-tail mean dose, while enforcing a cold-tail coverage constraint. This approach efficiently approximates a class of tail-controlled optimization goals that are often formulated as more computationally intensive problems.

The results should be interpreted in the context of the study design. EZFluence provides broader functionality (e.g., multiple candidate plan generation, fluence editing, and optional chest wall sparing). Our script focused narrowly on tangent whole-breast FIF planning using a fixed aperture count and a hotspot-focused weight refinement objective; therefore, the comparison is limited to this planning task and to our chosen evaluation endpoints.

CONCLUSIONS

An Eclipse v18 scripting workflow for whole-breast tangential FIF planning—combining fluence optimization, aperture extraction, and CVaR-based convex MU refinement—reduced hotspot volumes (V105%, V107%) compared with EZFluence under matched maximum dose normalization, while maintaining similar target coverage and heart/lung sparing. This approach provides an institution-configurable alternative when commercial automation does not meet local homogeneity objectives.