Development and Evaluation of an Automated Quantum-Inspired Optimization Framework for Partial-Breast IMRT.

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ABSTRACT

Purpose: To develop a streamlined and automated quantum-inspired optimization framework using mixed-integer quadratic programming (MIQP).

Innovation: This work presents a novel MIQP-based formulation for IMRT plan optimization and a streamlined, automated programming workflow that enables practical and reproducible evaluation of the proposed quantum-inspired optimization method.

INTRODUCTION

Modern radiotherapy techniques such as IMRT, VMAT, and IMPT rely on inverse optimization to achieve highly conformal dose distributions. While conventional optimization methods are effective, they can struggle with complex discrete planning problems. Mixed-integer quadratic programming (MIQP) naturally models these problems and is directly compatible with emerging quantum and quantum-inspired optimization approaches. This work presents a streamlined MATLAB-based automated MIQP framework for radiotherapy treatment planning and evaluates its performance for partial breast IMRT against a commercial treatment planning system.

METHODS AND MATERIALS

A quantum-inspired treatment planning framework based on a weighted quadratic cost function with integer beamlet intensities was developed in MATLAB using open-source MatRad functionalities. Custom MATLAB/MatRad scripts automated open pencil-beam fluence from clinically feasible beam angles. The MIQP formulation, encapsulated as a software library (C++), enabled automatic MIQP problem generation, parameter specification (python GUI), optimization (Gurobi), and import of optimized solutions into MatRad for plan evaluation and display. The workflow was applied retrospectively to seven partial-breast patients (30 Gy in 5 fractions). IMRT (step-and-shoot) plans from a clinical planning system and the quantum-inspired solver, both optimized using identical beam angles, were compared using dose–volume histogram (DVH) metrics; target coverage (PTV D95%), lung (V10Gy, V5Gy) and heart dose metrics (V3Gy).

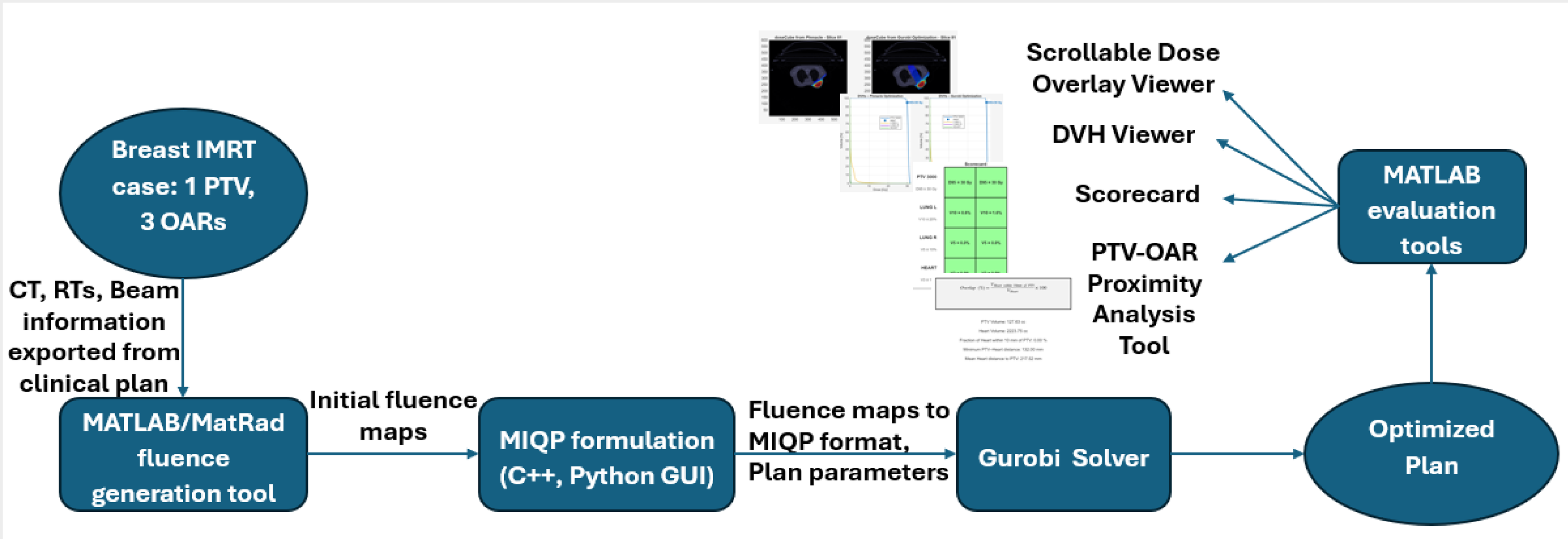

Figure 1: Automated quantum-inspired treatment-planning framework.

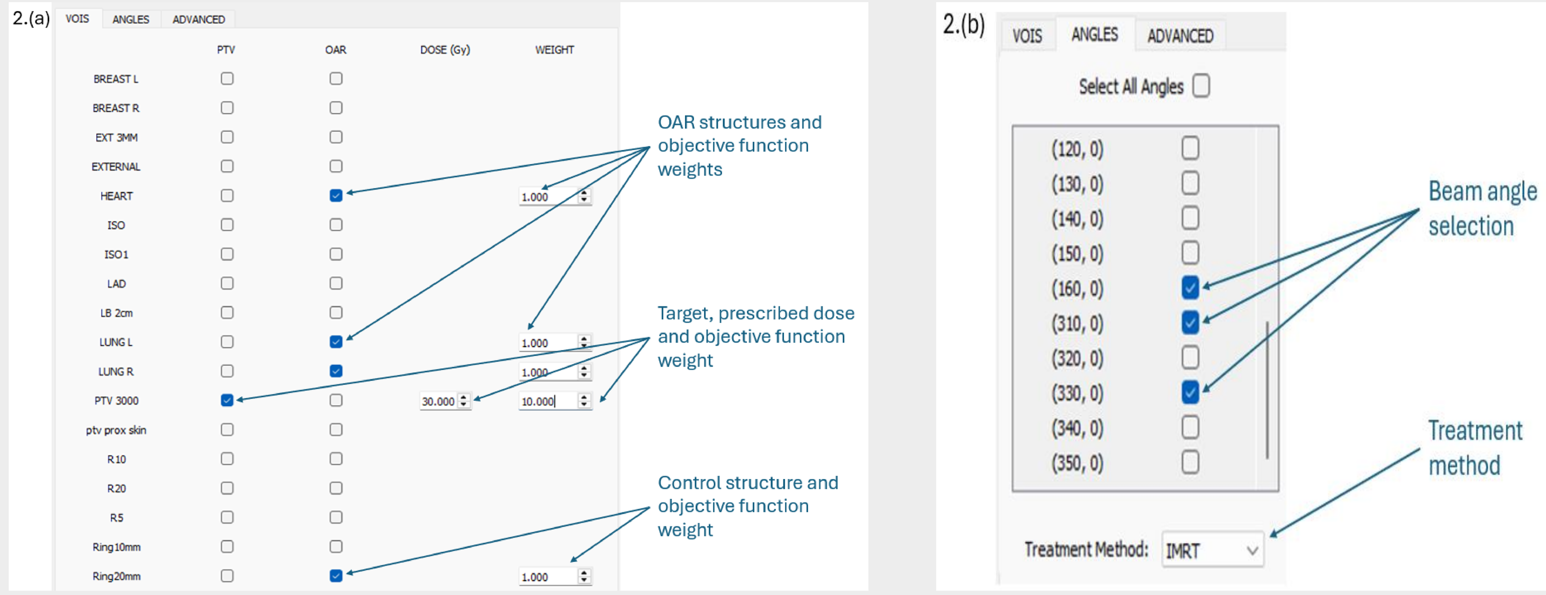

Figure 2: Python GUI (a). Defining target dose prescription, OAR dose restrictions, objective function weights. (b) Selecting beam angles, couch angles, and treatment method.

RESULTS

By encapsulating all components within a unified MATLAB-driven workflow, we eliminated manual, multi-environment processing and enabled automated plan optimization and evaluation. Quantum-inspired plans were generated reproducibly across all cases with minimal parameter adjustment with a single case runtime of under 10 seconds. Preliminary DVH comparisons demonstrated comparable target coverage (PTV D95% = 30 Gy for both) and organ-at-risk (OAR) sparing (Heart V3Gy = 1.2 ± 1.7% for quantum-inspired plans vs 1.7 ± 2.2% clinical plans. Ipsilateral lung V10Gy = 1.5 ± 1.0 % vs 2.0 ± 2.2%, contralateral lung V5Gy = 0.3 ± 0.5% vs 0.9 ± 2.3%, respectively). For quantum-inspired plans, observed inter-patient variability in dose metrics reflected differences in target–organ geometry.

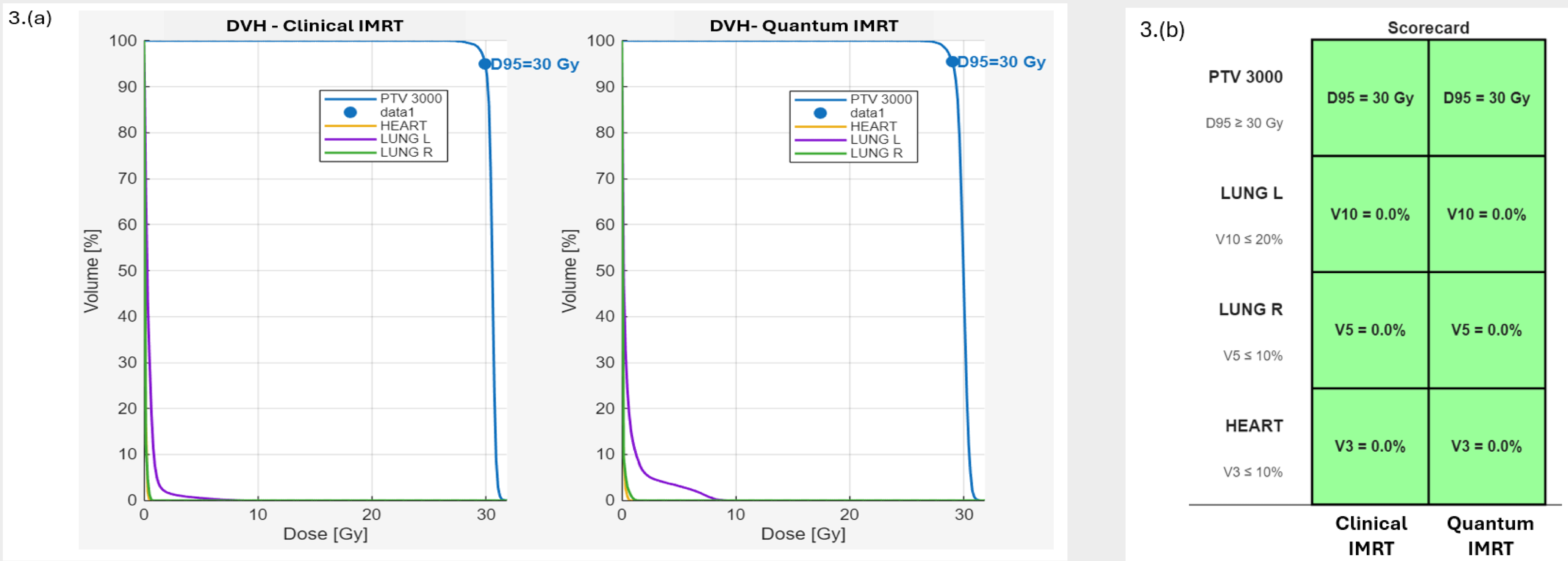

Figure 3. Comparison of clinical IMRT vs quantum-inspired IMRT for an example case. (a) DVH Viewer comparing the two plans. (b). Scorecard showing the dose constraints used for optimization and the achieved dose metric for the two plans.

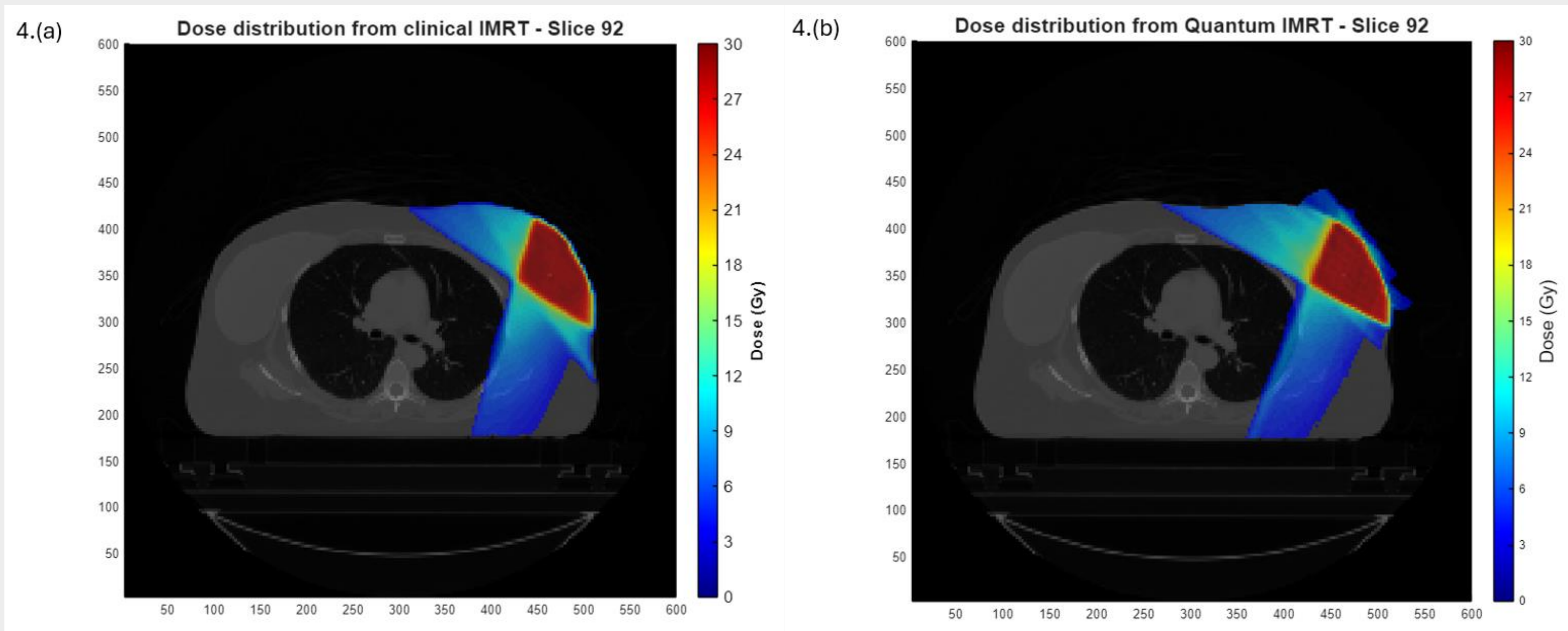

Figure 4. Scrollable Dose Overlay Viewer comparing the dose distributions of a clinical IMRT plan and (b) the dose distribution of the plan from the quantum-inspired optimization for the example case.

DISCUSSION

This streamlined and scalable software framework using MIQP formulation enables efficient, reproducible evaluation of quantum-inspired optimization methods and provides a foundation for ongoing studies aimed at improving plan quality at higher complexities. Future studies will further integrate software components, expand the patient dataset, explore beam angle optimization, and support IMPT.

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