

Abstract

- Conventional radiotherapy plan evaluation relies on isolated dose-volume metrics.
- However, dose-volume metrics provide limited insight into the magnitude and clinical significance of deviations from protocol-defined organ-at-risk (OAR) objectives.
- Propose a novel plan-level OAR dose deviation metric to quantify deviations from protocol-defined OAR objectives.
- OAR objective deviations provide a robust, scalable, and constraint-aware tool for benchmarking radiotherapy plans.
- Identify systematically challenging OAR objectives and provide objective plan quality-assurance.

Introduction

- Conventional scoring approaches rely on isolated dose-volume metrics which do not enable comparison across heterogeneous constraints.
- Developed a novel and interpretable plan-quality metric to quantitatively capture OAR objective deviations in a manner to allow normalized comparison across heterogeneous constraints.
- Measured the amount of deviation of the OAR objective's achieved value relative to the target value.
- Aggregated the relative deviation into a percentile-based score to enable comparison of approved radiotherapy plans in a constraint-aware method.
- Identified the most- and least-challenging constraints per OAR and per structure.

Methods

- Analyzed 288 left-breast and 294 right-breast approved tangent radiotherapy plans; each plan prescribed 42.56 Gy in 16 fractions.
- For each OAR objective, we defined:

$\text{constraint margin} = \text{achieved_value} - \text{protocol_defined_value}$

- Obtained relative constraint margin by normalizing to the objective's target to compare across OARs.
- Most challenging: relative constraint margin < 25th percentile.
- Least challenging: relative constraint margin > 75th percentile.
- Computed an average_score by averaging relative constraint margins across all OAR objectives.
- Plan score obtained by converting average_score for all approved plans into a percentile scale.

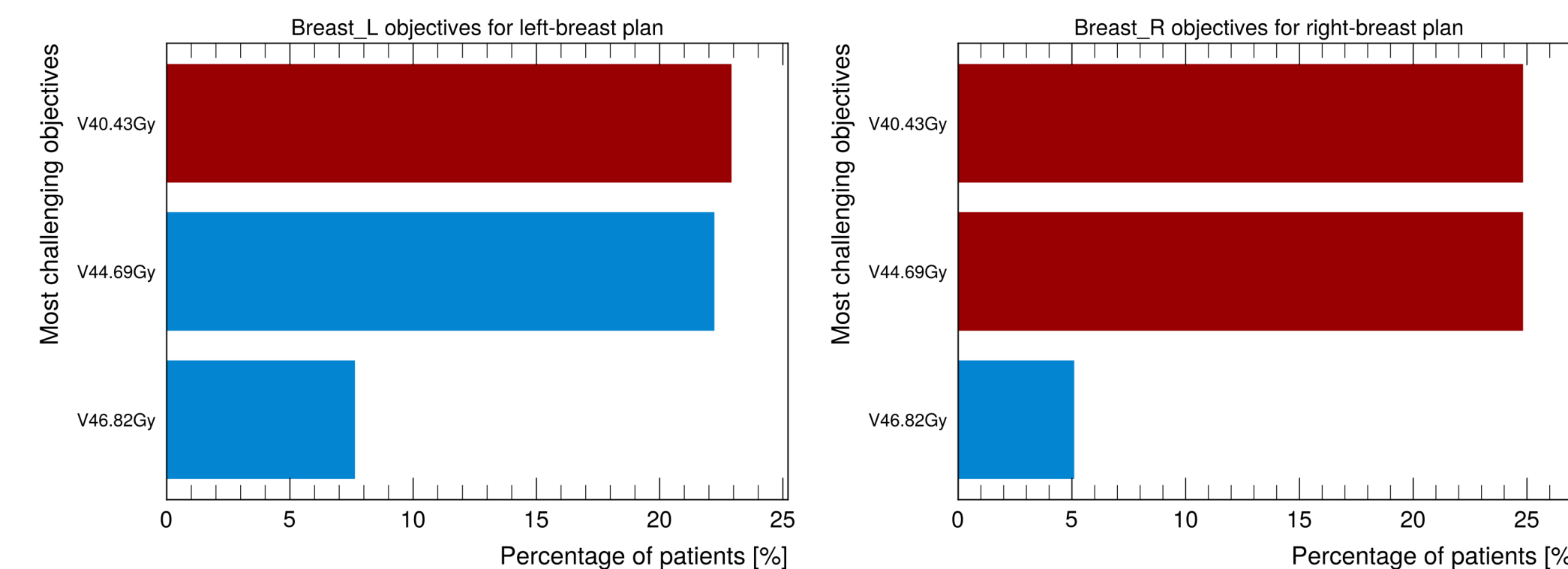


Figure 1. Bar plots showing the most challenging objectives for the left breast and right breast structures for left-breast and right-breast plans, respectively. V40.43Gy objective, shown in red, is the most-challenging objective for roughly 25% of the patient plans. For the right-breast plans, V44.69Gy is another challenging objective, with roughly 25% of the patient plans not meeting the constraint goal.

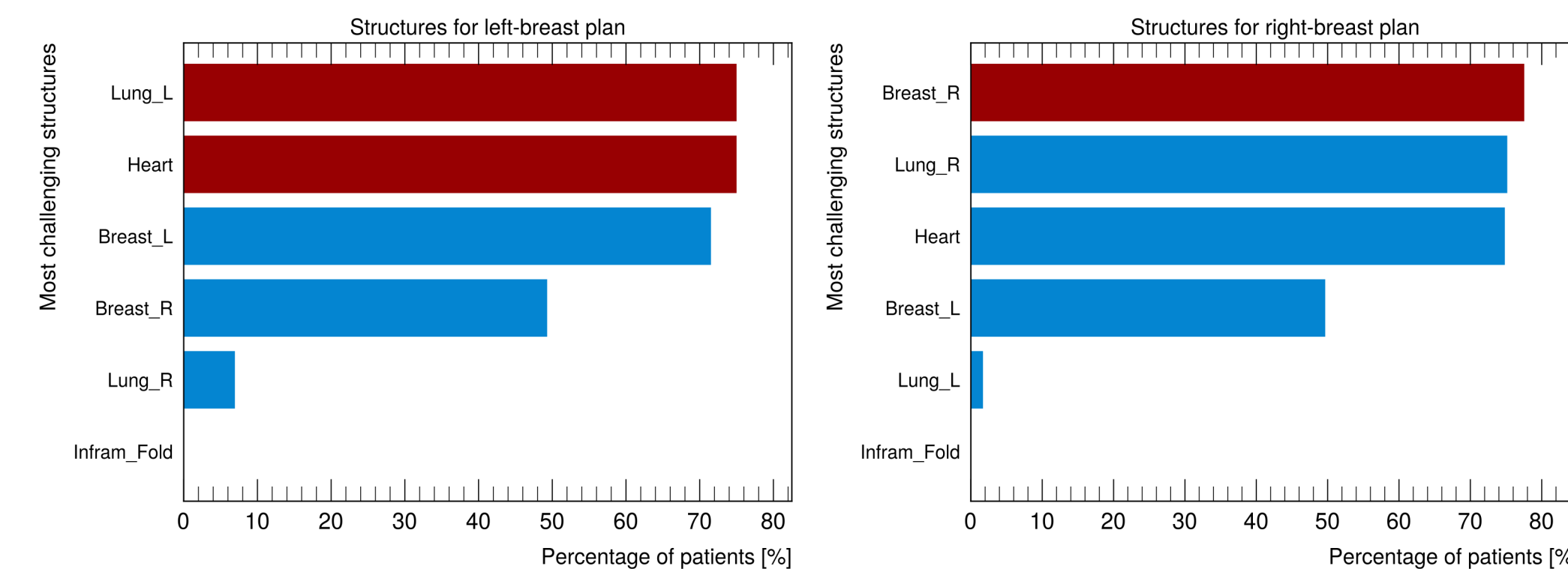


Figure 2. Bar plots showing the most challenging structures for left-breast and right-breast plans, respectively. The heart and the left lung are the most challenging structures for left-breast plans, reflecting their anatomical proximity to the target volume and unavoidable intersection with tangential beam paths.

Results

- Clinical and dose-volume data were extracted from 582 approved breast plans.
- Plans were evaluated against a standard institutional protocol.
- V40.43Gy objective for the breast PTV predominantly classified as the most challenging objective (Figures 1 and 2).
- Heart and left lung identified as the most challenging structure for left-breast plans (Figure 2)—consistent with known anatomical and dosimetric challenges.
- Constraint-aware plan score compared with a conventional plan-scoring method that counts fraction of objectives satisfied per plan.
- ECDF analysis of paired score differences showed that 60% of plans achieved higher scores under the constraint-aware metric, with a median score change of 1.04 (IQR: −1.85 to 3.68) (Figure 3).

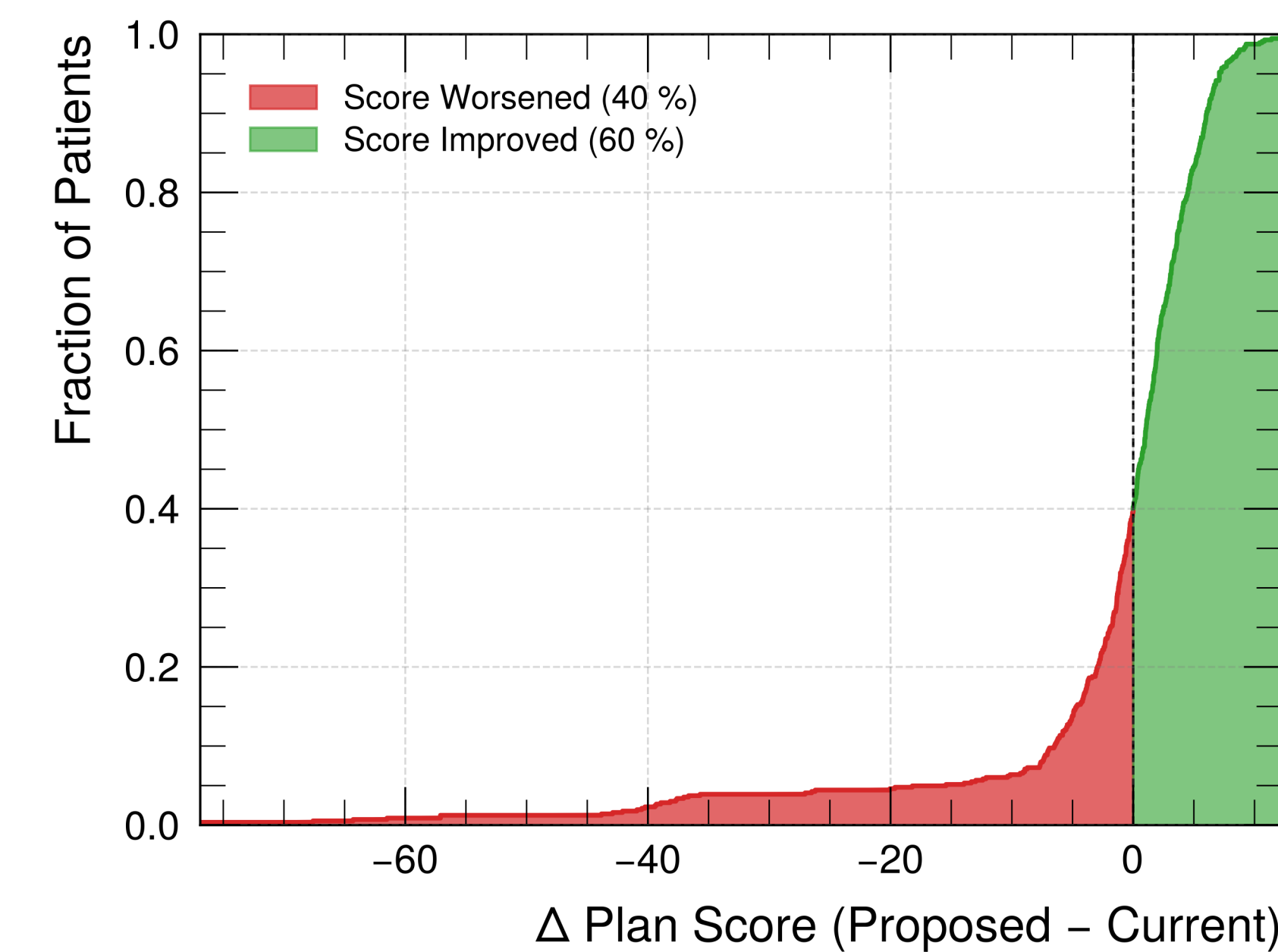


Figure 3. ECDF distribution of the paired score differences between the proposed and the current plan score. The proposed plan score is computed by aggregating the relative constraint margins across all objectives and mapping the aggregate value to a percentile scale. The current plan score is computed by counting the fraction of objectives satisfied per plan. 60% of plan scores improved on the constraint-aware scoring metric. The worsened plan scores highlight the efficacy of the proposed plan score to provide improved discrimination beyond a pass/fail metric for evaluation patient plans.

Discussion

- Conventional pass/fail scoring treats all objectives equally and ignores how close a plan is to the protocol limits.
- Constraint-aware plan score offers improved discriminatory power over conventional approaches which rely on binary pass/fail criteria or isolated dose-volume metrics.
- ECDF results where 60% of plans received higher scores under the new metric suggest improved sensitivity for ranking clinically acceptable plans.
- Relative constraint margin enables direct comparison of different OARs, overcoming major limitation with raw dose differences or constraints with different units and scales.
- Proposed plan scoring approach has the potential to enhance plan evaluation consistency, facilitate large-scale protocol compliance analysis, and inform automated and adaptive treatment planning strategies.
- Current metric developed and evaluated using breast radiotherapy plans from a single treatment protocol.
- Generalizability to other disease sites, prescription schemes, and planning techniques remains to be established.
- Future work should validate the approach across multiple institutions, compare with expert scoring, and explore weighing objectives according to their relative clinical importance.

Conclusions

- Constraint-aware plan-scoring quantifies deviations from protocol-defined targets and identifies the most- and least-challenging OAR objectives.
- Constraint-aware scoring metric provides a more informative assessment of radiotherapy plan quality than conventional pass/fail evaluation by incorporating the magnitude of deviations from protocol-defined objectives.
- Normalizing constraint margins enables consistent, comparative evaluation of plan quality across patients and plan types.
- Constraint-aware plan score provides better analysis of plan-score quality beyond conventional pass/fail scoring.

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