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Toward Clinical Adoption of Open-Source Radiotherapy Linac Quality Assurance Tools: A Scoping Review and Benchmarking Analysis

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ABSTRACT

Background:
- Open-source quality assurance (OSQA) software packages offer potential value in resource-constrained radiotherapy settings.
- Gaps in validation, standardization, and implementation guidance may limit clinical adoption.

Objective:
- Develop a structured characterization process for OSQA software packages.
- Benchmark select candidates on tests aligned with AAPM TG-142.

Methods:
- Candidate software: PRISMA scoping review of Embase, PubMed, and Web of Science; advanced search of public GitHub repositories; targeted web search.
- Screening: Automated grouping by category; filtration for TG-142 relevance and implementation feasibility; classification into tiers.
- Benchmarking: Varian TrueBeam data from monthly TG-142 tests at UCSF and UCLA.

Results:
- 991 literature records and 79 GitHub repositories screened.
- 27 OSQA candidates identified; 10 implemented and tested.
- Mechanical and radiation QA tests (Winston-Lutz, field analysis, picket fence) showed strong agreement with commercial software.
- Imaging QA tools had more variability in executability and quantitative agreement.
- Summary reports were generated for each implemented software.

Conclusions:
- Several OSQA packages can facilitate TG-142 tests and agree with commercial software.
- Standardized validation and implementation guidance are needed to support clinical adoption, particularly in resource-constrained settings.
- This charge is under review for AAPM TG473.

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INTRODUCTION

Quality assurance (QA) of C-arm linear accelerators (linacs) is guided by consensus frameworks such as AAPM TG-142 and MPPG 8a [1-2].

Increased technological complexity in radiation therapy is accompanied by greater QA demands. Many clinics rely on commercial image- and log-file analysis software to improve the efficiency and robustness of their QA protocols.

Open-source software packages for radiotherapy quality assurance (OSQA tools) are increasingly available in publications and code repositories, but the degree of validation, standardization, and documentation varies. Addressing these gaps may improve the utilization of OSQA tools, especially in resource-constrained clinics, where commercial QA software may be cost-prohibitive to purchase or maintain.

METHODS AND MATERIALS

Study Design
1. Candidate software selected with scoping review and Github advanced search (**Fig. 1**).
2. Tier-based classification of relevant OSQA tools (**Table 1**).
3. Benchmarking data set collection (**Fig. 2**).
4. Clinical benchmarking of OSQA tools against commercial software (**DoseLab™, RadMachine™**).

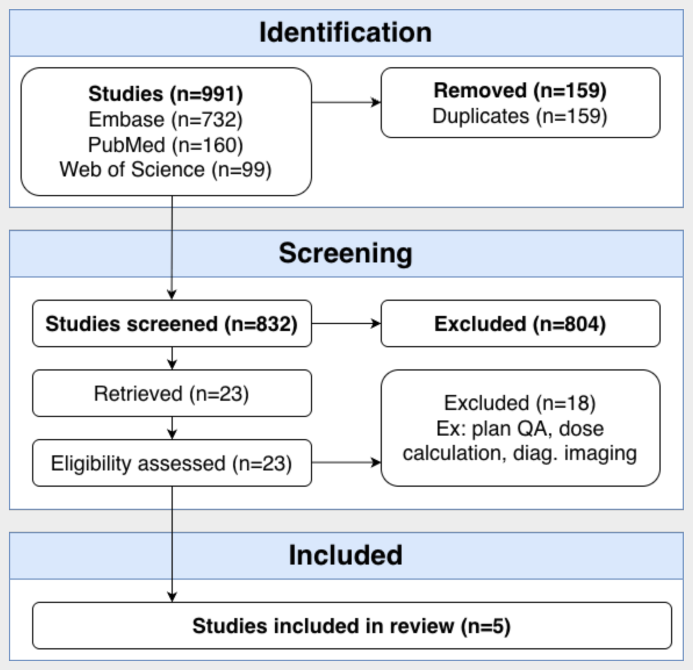
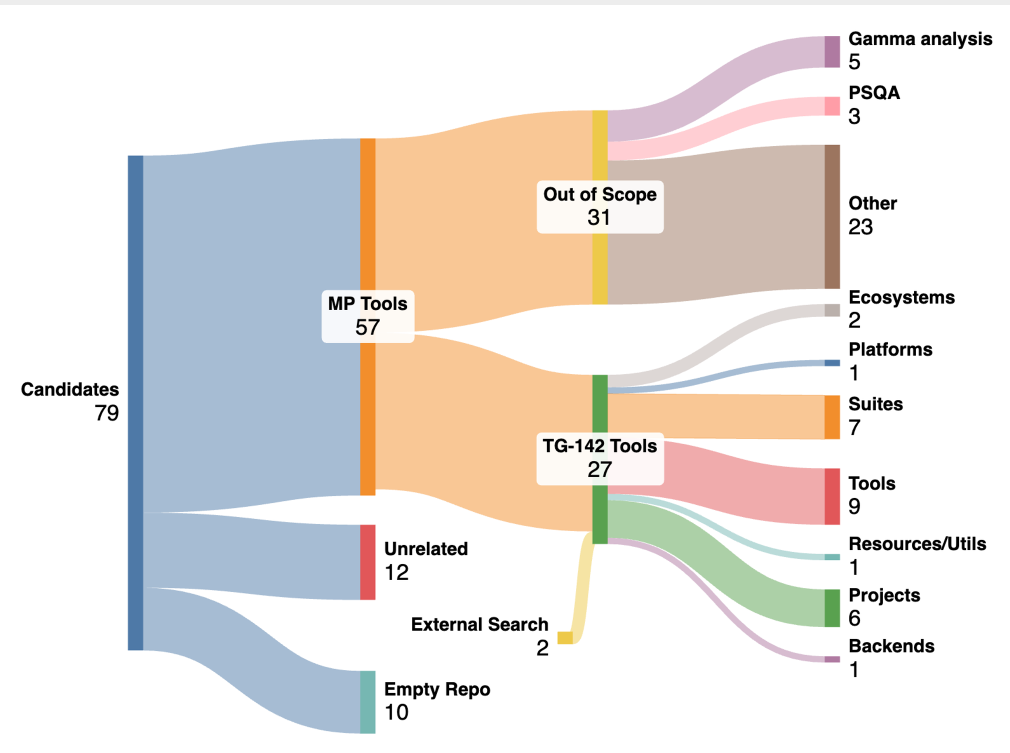


Figure 1. OSQA tool landscape. (Left) PRISMA-compliant scoping review and screening for classification and inclusion in benchmarking study.

(below). Github repository advanced search and manual screening outcomes.



Tiers	Description of features
Backend	Customizable package for integration into a tool
Tool	GUI, web interface, or wrapper that facilitates 1 QA test
QA Suite	GUI, web interface, or wrapper that facilitates 2+ QA tests
Platform	QA tool with database and/or trending analysis
Ecosystem	QA suite with database, trending, and multiple machines

Table 1. Pre-defined tiers for OSQA classification.

RESULTS

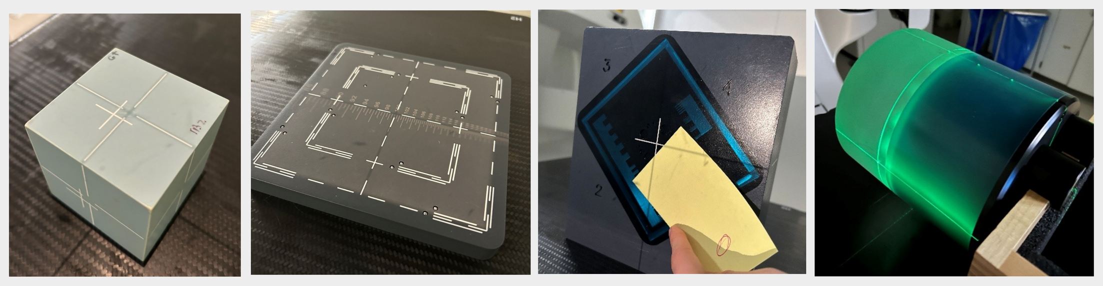


Figure 2. Phantoms for benchmarking data set. (Left to right) WL3 Winston-Lutz, RLf radiation field, MC2 Mobius planar imaging, Catphan 504 CBCT.

Winston-Lutz Test (5 OSQA packages)

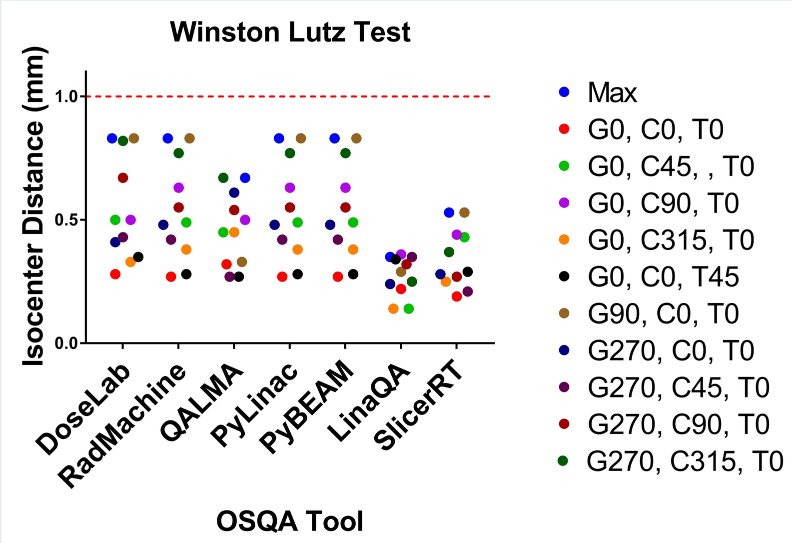


Figure 3. All OSQA results agreed with pass/fail verdict (tol: 1 mm). Mean deviation: 0.14 mm (range 0—0.57 mm).

3 packages (PyLinac, PyBeam-QA, RadMachine) share the same PyLinac module and identical results.

MLC Positional Accuracy (3 OSQA packages)

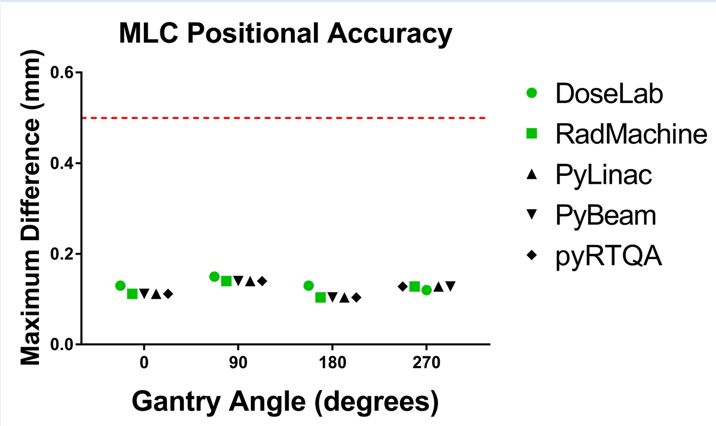


Figure 4. All OSQA results agreed with pass/fail verdict (tol: 0.5 mm).

Radiation Field Analysis (4 OSQA packages)

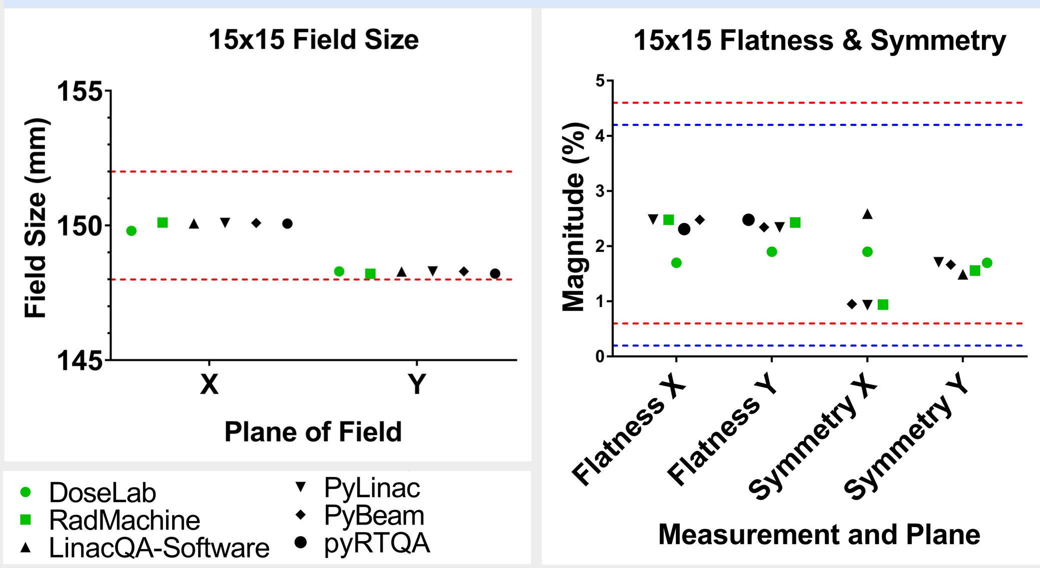


Figure 4. Strong agreement for field size, flatness (0.39% (10×10 cm²) / 0.17% (15×15 cm²)). Symmetry discrepancies up to 1.4% for 15×15 cm² may reflect different definitions in software.

Image Analysis (3 OSQA packages)

- Only Pylinac completed all tests for kV/MV and CBCT.
- 2 other tools provided some CBCT tests (**Table 2**).

OSQA Software	Scan Protocol	Magnitude Difference from DoseLab™: MTF 50% (lp/mm)	CNR (HU)	Max HU Deviation (HU)	Slice Width (mm)
PyLinac	Pelvis	0.08	0.6	3	0.613
Automated-RTQA	Pelvis	0.08	N/A	N/A	0.613
pyRTQA	Pelvis	0.08	N/A	N/A	N/A

Table 2. Comparison of OSQA software output against DoseLab software for CBCT imaging analysis.

Log-File Analysis (1 OSQA package)

- Sentinel-Public achieved 100% pass/fail agreement with the in-house UCLA log-file workflow across vendor and patient-specific plans.

DISCUSSION

- Fragmented OSQA landscape: many repositories are inactive, partially implemented, or poorly documented.
- Tier framework: clarifies scope and complexity to help clinics match tools to their needs.
- Mechanical/radiation QA tools: showed clinically acceptable agreement with commercial software.
- Imaging QA tools: less flexible for application to the benchmarking data set, reflecting complexity in configuration and file types.
- 6 of 10 tools tested rely on Pylinac as a backend, including commercial RadMachine. Clinics that can accept a steeper initial learning curve may derive high value from using Pylinac directly.
- Findings are especially relevant to resource-constrained settings, where commercial QA software may be cost-prohibitive.

Limitations:
- Single linac platform (Varian TrueBeam);
- Single phantom per test type;
- Limited effort spent debugging software.

Future work:
- Develop standardized validation datasets for multiple platforms, vendors, and QA workflows.
- Develop a rubric to support evidence-based OSQA adoption.

Open-Source Software	Tier	Agreement with vendor software: WL	Field	MLC	kVMV	CBCT	Log
QALMA	QA Suite	✓					
Pylinac	Backend	✓	✓	✓	✓	✓	
LinacQA-Software	QA Suite		✓				
Sentinel-Public	Platform						✓
PyBeam-QA	QA Suite	✓	✓	✓			
LinaQA	QA Suite	✓					
QA-routine-pylinac-based	QA Suite						
Automated-Rt-QA	QA Suite						
pyRTQA	QA Suite		✓	✓			
SlicerRT	QA Suite	✓					

Table 3. Summary of ten OSQA tools evaluated for usability and benchmarked against commercial software. ✓: Test successfully executed and quantitatively agreed with vendor software results.

CONCLUSIONS

Several OSQA tools can achieve performance comparable to commercial software on image- or log-based tests for TG-142 QA. However, availability alone does not indicate clinical readiness. These findings support minimum evaluation standards and an implementation toolkit for safe, scalable adoption in resource-constrained settings.

REFERENCES

1. E. E. Klein et al., "Task Group 142 report: Quality assurance of medical accelerators," *Med Phys*, vol. 36, no. 9 Part1, pp. 4197–4212, 2009.
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