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Validation of an automatic ACR phantom quality assurance tool for the low-field MR guided radiotherapy system

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INTRODUCTION

MRI has been increasingly incorporated in every step of radiation oncology workflow to take advantage of its superior soft tissue contrast for organ and tumor delineation. To ensure the acquired images are of sufficient quality for treatment planning and guidance, quality assurance (QA) is essential.

The American College of Radiology (ACR) phantom test is one of the most well-known QA phantoms to evaluate the MRI scanner imaging performance. However, manual ACR analysis is labor-intensive and prone to observer variability. Several commercial and open-source toolboxes have been developed for automatic ACR QA at standard 1.5T or 3T field [1-3]. However, one of the MR guided radiotherapy (MRgRT) vendors adopted a low-field MR design (0.35T), and the ACR test criterion is slightly different from the standard MR scanner. Therefore, it is necessary to modify and validate the automatic ACR QA tool for the low field system.

AIM

- To assess whether an automatic ACR phantom analysis toolbox could be used to facilitate ACR QA on low-field MR guided radiotherapy systems.

METHOD

- Several modifications were made on an open source automatic ACR QA toolbox [1] to adjust the testing procedure differences for the low-field MRI QA.
- A total of 17 ACR datasets were collected,
  - 10 datasets obtained from the vendor on different machines at various centers across the world
  - 7 datasets acquired at our center from 2014 to 2020
- Manual and automatic measurements were compared on five ACR tests
  - Geometric accuracy (GA)
  - High-contrast spatial resolution (HCSR)
  - Slice thickness accuracy (ST)
  - Slice position accuracy (SP)
  - Percent integral uniformity (PIU)
  - Percentage signal ghosting (PSG)
- Evaluation matrices
  - Absolute difference
  - Precision (the rate of a predicted pass that is a true pass),
  - Recall (the rate of identifying a true pass test),
  - Accuracy (the rate of a predicted pass/fail is a true pass/fail)

RESULTS

For the five ACR tests, the automatic QA toolbox reduced the analysis time from approximately 40 minutes or more to less than 1 minute.

Figure 1 shows the ccomparison of manual and automatic measurements. Overall, there were good agreements of the two measurements.

Three automatic GA measurements were out of the tolerance due to a big air bubble in the phantom (Figure 2(a)).

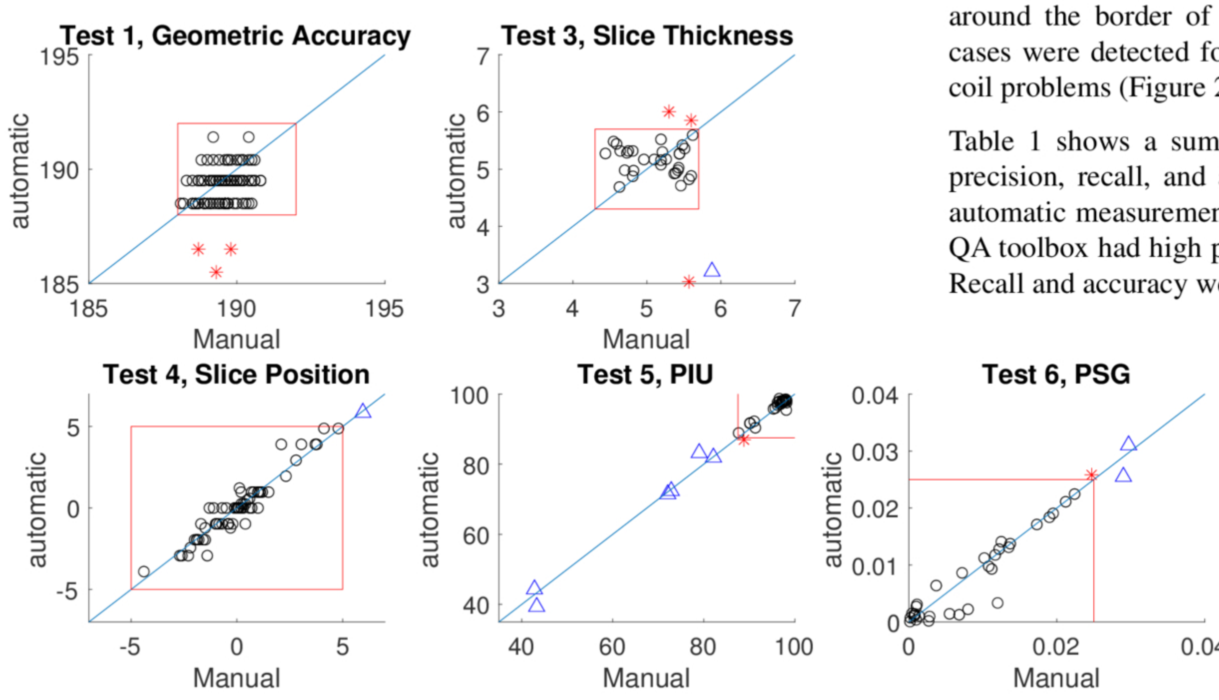

Figure 1. Plot of manual versus automatic measurements. The blue line represents the identical line. The red rectangular indicates the measurement tolerance. Black circle represents both manual and automatic measurements passed the testing criteria (true positive). Red start represents the manual test passed the test while the automatic output failed the test (false negative). The blue triangle represents both manual and automatic failed the test (true negative). There was no data where the manual measurement failed but automatic measurement passed (false positive).

The ST test is the most challenging test as the length measurement of the slice thickness ramp is dependent on the display window level. physicists usually adjust display level on a case by case fashion, which is not feasible for the automatic QA toolbox (Figure 2 (b) (c)).

For the SP test, manual and automatic measurements had 100% agreement on the fail/pass decision. The one failure case was caused by inappropriate imaging slice location prescription (Figure 2 (d)).

For both PIU and PSG tests, good correlation between manual and automatic measurements were observed. There was one false negative case for both PIU and PSG tests. However, the measurements were around the border of the passing criteria. A couple of true negative cases were detected for the PIU and PSG tests due to system issue or coil problems (Figure 2 (e)).

Table 1 shows a summary of the absolute difference as well as the precision, recall, and accuracy of the automatic toolbox. Overall, the automatic measurements were close to manual analysis. The automatic QA toolbox had high precision (true passing rate) of 1 for all five tests. Recall and accuracy were ≥0.96 for GA, SP, PIU and PSG tests..

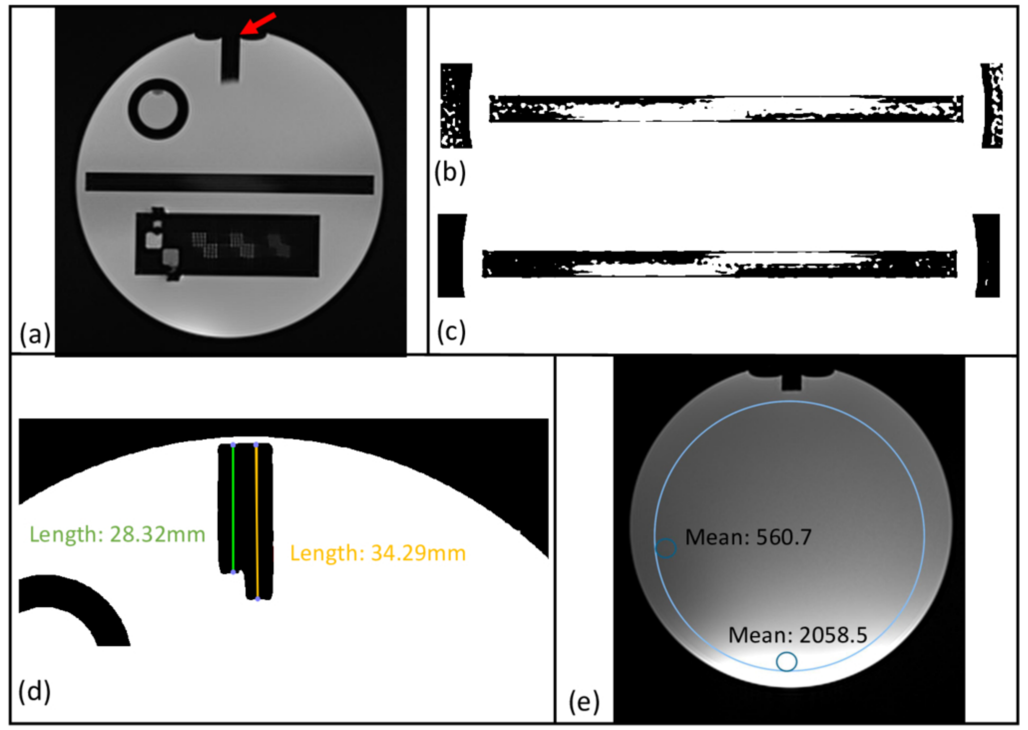

Figure 2. Examples of some cases. (a) The automatic QA toolbox failed due to the air bubble inside the phantom. (b) An example of the slice thickness test where the display level was lowered to half of the mean ramp signal according to the ACR recommendation. (c) The same image of (b) but the display level was increased by 20. (d) The slice position test failed due to inappropriate imaging slice prescription. (e) An example of a case where the PIU failed due to bad coil element.

Table 1. Summary of performance of the automatic QA software. The absolute difference between manual measurement and automatic measurement, precision, recall, and accuracy were reported.

		GA	ST	SP	PIU	PSG
Absolute difference	Mean±SD	0.72±0.66 (mm)	0.50±0.60 (mm)	0.39±0.41(mm)	1.01±1.00 (%)	0.0016±0.0019
	Maximum	3.80 (mm)	2.67 (mm)	1.81 (mm)	4.22 (%)	0.0087
Precision		1.00	1.00	1.00	1.00	1.00
Recall		0.97	0.91	1.00	0.96	0.97
Accuracy		0.97	0.91	1.00	0.97	0.97

CONCLUSIONS

- An automatic ACR QA toolbox was modified and evaluated for the low-field MR guided radiotherapy system.
- The software provided comparable results as manual analysis, and reduced the processing time from over 40 minutes to less than 1 minutes.
- Further study is needed to improve the slice thickness calculation.

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