Standardizing MRI Image Quality QA for Gamma Knife SRS and fSRS Across a Multicampus Radiation Medicine Network

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Gamma Knife (GK) stereotactic radiosurgery (SRS) and fractionated SRS (fSRS) planning require high-fidelity MRI to ensure accurate target delineation with minimal planning margins. In this work, MRI image quality was evaluated across multiple diagnostic MRI systems spanning a multicampus radiation medicine network using Gamma Knife planning parameters and ACR phantom-based quality assurance methods.

ACR MRI phantom scans were acquired on 1.5 T systems using stereotactic protocols including 1 mm slice thickness, 256×256 matrix, and no angulation, with sequences such as T1 MPRAGE, T2, T2 FRFSE, and T2 FIESTA. Image quality was assessed using four ACR metrics: high-contrast spatial resolution (HCSR), image intensity uniformity (IIU), percent signal ghosting (PSG), and low-contrast object detectability (LCOD). All systems met ACR acceptance criteria, with HCSR of 1.0 mm in most cases, IIU ranging from 0.8895 to 0.9600, PSG below 2.5%, and LCOD demonstrating high detectability across sequences.

However, sequence- and protocol-dependent variability was observed, particularly in PSG and LCOD. These findings support the development of standardized, sequence-specific QA baselines and internal action limits to enable a centralized, vendor-independent MRI QA framework for radiosurgery planning.

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INTRODUCTION

Gamma Knife SRS and fSRS rely heavily on MRI for precise target delineation, where even small deviations in image quality can directly impact contour margins and treatment confidence. While MRI quality assurance is well established in diagnostic imaging, its application in radiation therapy, particularly for stereotactic procedures, requires stricter performance consistency and reproducibility. Current guidelines such as AAPM TG-178 and TG-284 emphasize the importance of MRI QA in radiotherapy but do not fully address multicampus standardization across vendors and protocols. This work seeks to address that gap by evaluating MRI image quality across a distributed network and reframing QA metrics as clinically relevant indicators of stereotactic accuracy, rather than purely diagnostic benchmarks.

METHODS AND MATERIALS

ACR MRI phantom scans were acquired on 1.5-tesla MRI systems across multiple campuses and vendors to evaluate cross-site consistency under clinically relevant conditions. All primary acquisitions used Gamma Knife planning parameters, including 1 mm slice thickness, 256×256 matrix, and no slice angulation or overlap, with sequences including T1 MPRAGE, T2, T2 FRFSE, and T2 FIESTA.

At one site, an additional phantom scan was performed using standard ACR parameters with 5 mm slice thickness to assess protocol dependence. Image quality was evaluated using four ACR-defined metrics: high-contrast spatial resolution (HCSR) to assess edge definition, image intensity uniformity (IIU) to evaluate signal homogeneity, percent signal ghosting (PSG) to quantify artifact presence, and low-contrast object detectability (LCOD) to assess visibility of subtle structures. These metrics were analyzed across all sites to establish baseline performance and assess variability associated with sequence selection and acquisition protocol.

RESULTS

Across all MRI systems, high-contrast spatial resolution was 1.0 mm for most sequences, with one system achieving 0.9 mm, indicating sufficient spatial resolution for stereotactic contouring. Image intensity uniformity exceeded ACR acceptance criteria for all scans, ranging from 0.8895 to 0.9600, demonstrating stable signal homogeneity across vendors and sites. Percent signal ghosting remained well below the ACR threshold of 2.5%, with values ranging from 0.090% to 1.461%, and the highest ghosting observed in T2 FRFSE sequences, highlighting sequence-dependent artifact behavior. Low-contrast object detectability showed full detectability (10/10 spokes) in most sequences at 1.4% contrast, although one T2 Gamma Knife acquisition demonstrated slightly reduced performance (9/10 spokes).

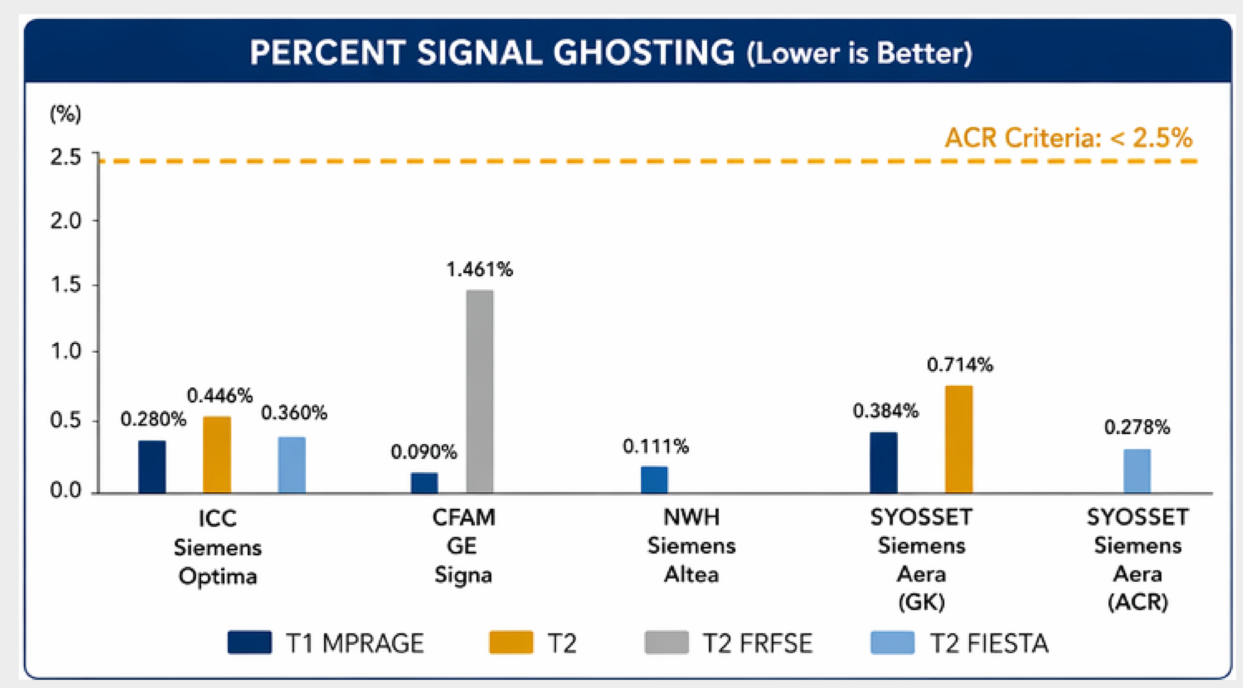

Figure 1. Percent Signal Ghosting

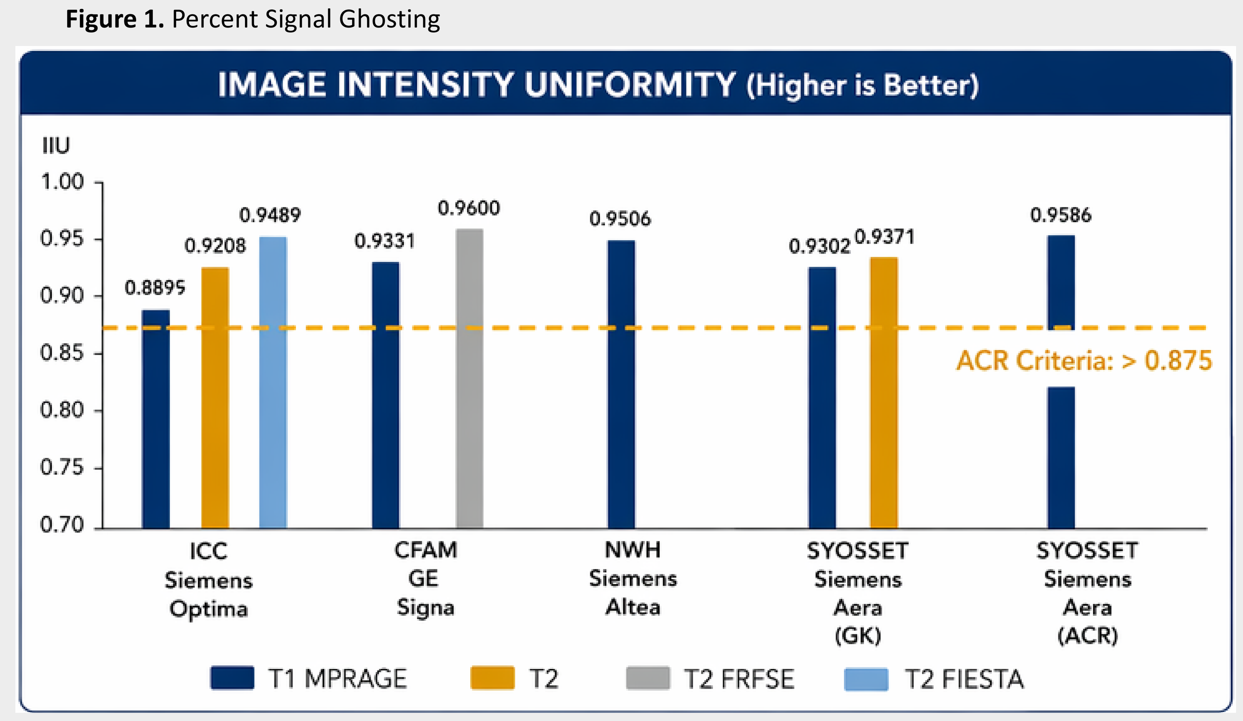

Figure 2. Image Intensity Uniformity

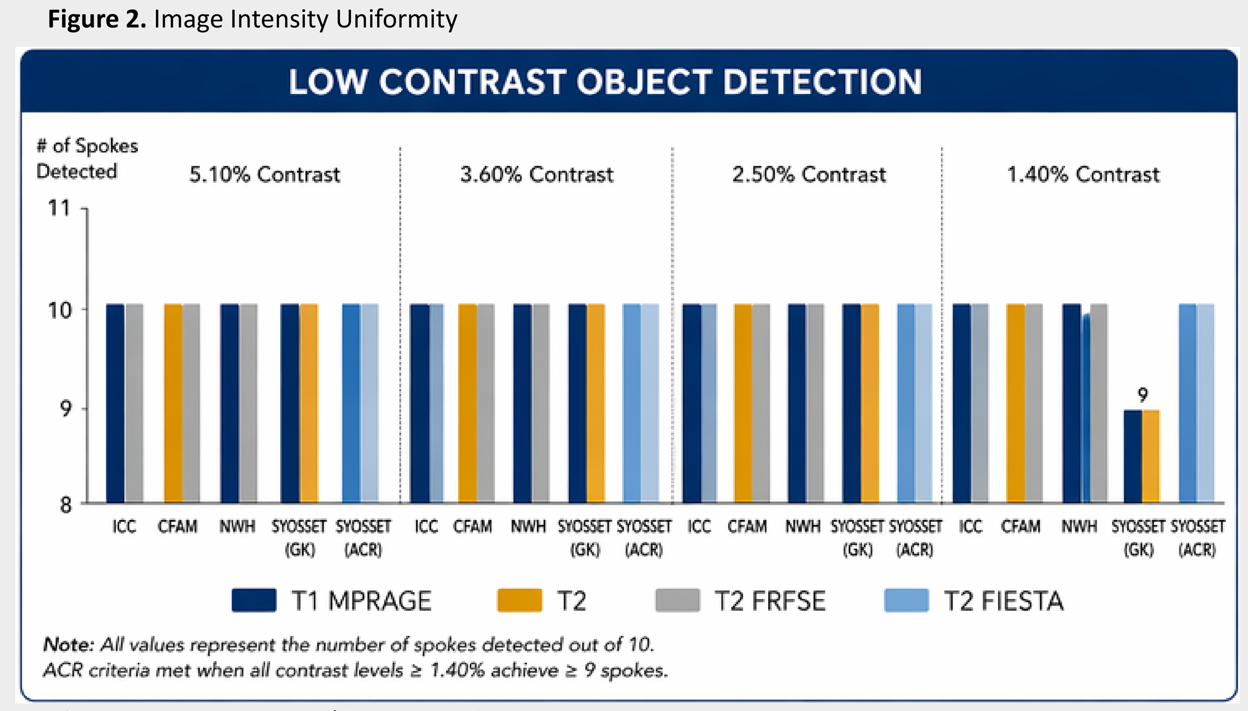

Figure 3. Low Contrast Object Detection

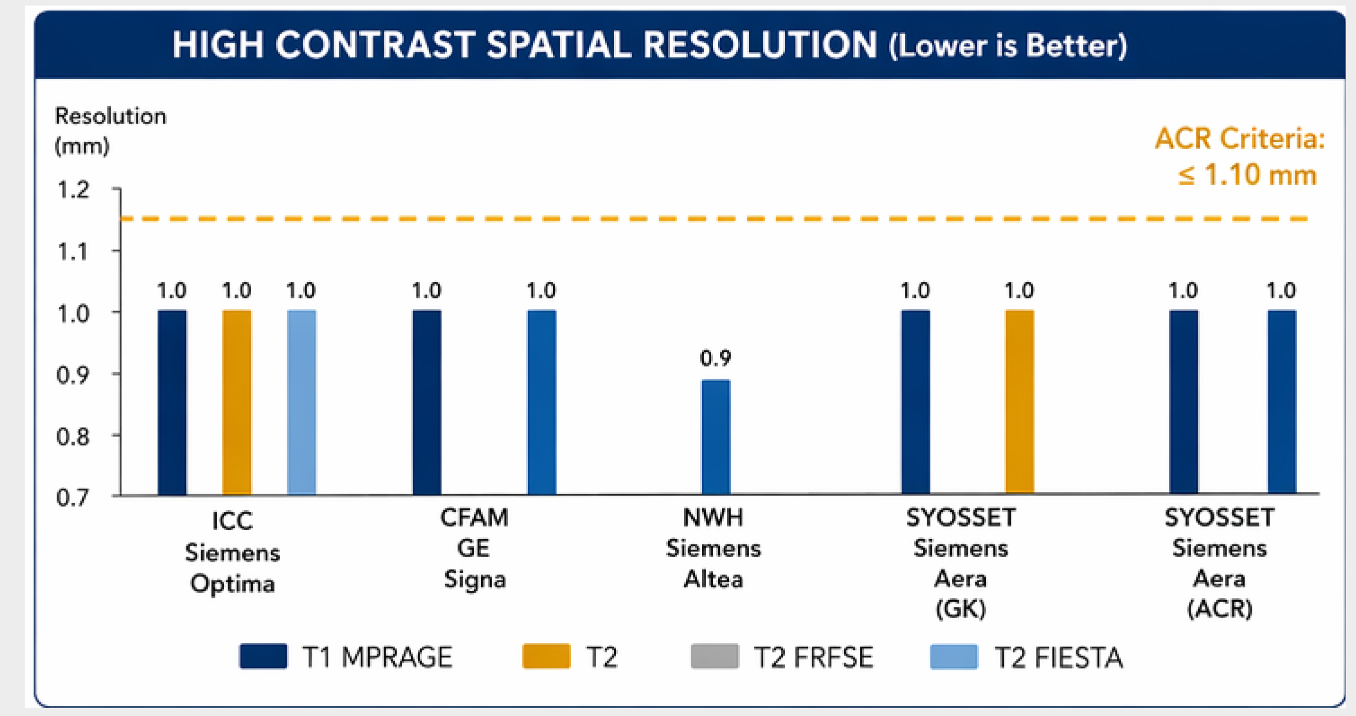

Figure 4. High Contrast Resolution

DISCUSSION

These results demonstrate that while all systems meet ACR acceptance thresholds, clinically relevant variability exists depending on imaging sequence and acquisition protocol. Differences in PSG and LCOD highlight that ACR pass/fail criteria alone may not fully capture performance requirements for stereotactic radiosurgery. The comparison between Gamma Knife and standard ACR protocols reveals that acquisition parameters can influence low-contrast detectability, which is critical for delineating small or poorly defined targets.

This work supports the need for sequence-specific baselines and internal action limits tailored to radiotherapy applications. Furthermore, the implementation of a centralized QA framework enables trending of image quality metrics, facilitating early detection of system drift and improving cross-site consistency. By reframing MRI QA as a therapeutic safety metric, this approach directly links image quality performance to clinical outcomes in SRS and fSRS planning.

CONCLUSIONS

These findings demonstrate that protocol selection can influence clinically relevant image quality even within accepted limits. Establishing Gamma Knife–specific QA baselines and internal action limits, consistent with AAPM TG-178 and TG-284, provides a pathway for harmonizing MRI performance across sites. This standardized, vendor-neutral framework enables centralized monitoring, improves contour confidence, and supports consistent, high-quality imaging for SRS and fSRS treatment planning.

REFERENCES

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