Novel Calibration Approach for Surface Guided Radiotherapy in Patients with Diverse Skin Reflectance: An Indian Experience

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ABSTRACT

Purpose:
Surface-Guided Radiation Therapy (SGRT) improves patient positioning and motion management in radiotherapy; however, optical performance may be influenced by skin reflectance. This study developed low-cost skin-tone phantoms representative of the Indian population and evaluated the impact of skin tone on SGRT registration accuracy using a C-RAD system.

Methods:
Custom mannequins representing a range of Indian skin tones were fabricated using locally available materials. SGRT surface registration performance was assessed under different camera exposure settings. Translational and rotational deviations were analyzed to determine the influence of skin tone on surface reconstruction accuracy.

Results:
Skin tone affected SGRT surface acquisition and registration performance, with darker skin tones showing increased sensitivity to camera exposure settings. Optimized exposure parameters improved surface reconstruction quality and reduced positioning uncertainties across all skin-tone categories.

Conclusions:
This study presents a novel, cost-effective skin-tone phantom for SGRT quality assurance. The findings demonstrate the importance of exposure optimization to ensure accurate and equitable SGRT performance across diverse patient populations, particularly in resource-constrained settings.

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INTRODUCTION

- SGRT is increasingly adopted for patient positioning and motion management in radiotherapy, improving treatment accuracy and patient safety.
- However, in low- and middle-income countries (LMICs), implementation of advanced technologies such as SGRT is often challenged by limited resources, workforce constraints, and restricted access to specialized training and technical support.
- As SGRT relies on optical surface imaging, its performance may be influenced by skin reflectance characteristics.
- This is particularly relevant in India, where skin complexion varies widely across the population.
- Darker skin tones absorb more light and may reduce surface detection accuracy, yet no standardized phantom currently exists to evaluate this effect.
- To address this gap, we developed low-cost skin-tone phantoms using locally available materials to represent the Indian patient population and investigated the impact of skin tone on SGRT camera performance and exposure optimization.

METHODS AND MATERIALS

- Three mannequins representing light, medium, and dark skin tones commonly observed in the Indian population were developed using commercially available makeup foundation shades (Lakme).
- The phantoms were evaluated using two C-RAD SGRT systems: the Sentinel (single-camera system) during CT simulation and the Catalyst HD (three-camera system) in the treatment room.
- Key acquisition parameters, including Threshold and Integration Time for the Sentinel, and Gain and Integration Time for the Catalyst HD, were systematically varied.
- Surface reconstruction performance was assessed based on surface continuity, absence of voids, and the level of topographic detail required for accurate patient positioning and motion tracking.

Figure 1. Cost-Effective Skin-Tone Mannequins Developed for SGRT Evaluation

RESULTS

- Skin tone significantly influenced SGRT surface acquisition and reconstruction.
- For the Sentinel system, complete surface coverage required integration times up to 3.8× the vendor-recommended default for light- and medium-tone phantoms and up to 6× for the dark-tone phantom.
- Threshold values below 300 resulted in noisy or incomplete reconstructions, while a threshold of 300 provided stable surface generation across all skin tones.
- For the Catalyst HD system, optimal surface registration was achieved using a gain of 567% with increased integration times (2× default for the light-tone phantom and ≥3× default for the medium- and dark-tone phantoms).
- These findings indicate that vendor default settings may be insufficient for darker skin tones and that optimization of acquisition parameters can substantially improve surface reconstruction and registration accuracy.

Table 1. Comparison of Vendor-Default and Optimized Catalyst HD Camera Acquisition Parameters for Skin-Tone Phantoms.

Settings	Sensitivity	Camera					
		Right		Mid		Left	
		Time (µs)	Gain	Time (µs)	Gain	Time (µs)	Gain
Default	Low	1500	400	1500	400	1500	400
	Med	2000	400	2000	400	2000	400
	High	2500	400	2500	400	2500	400
Optimal	Low	3000	567	3000	567	3000	567
	Med	7000	567	5500	567	6000	567
	High	7500	567	5500	567	7250	567

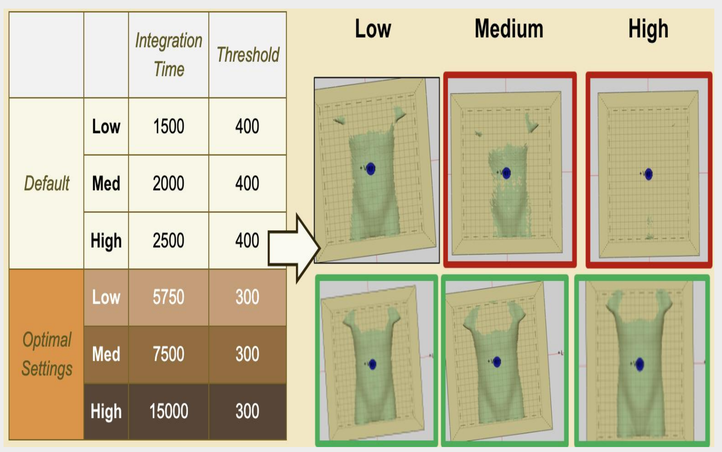

Figure 2. Increased Sentinel Integration Time Requirements for Darker Skin-Tone Mannequins

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DISCUSSION

- This study demonstrates that skin tone influences SGRT surface acquisition due to differences in optical reflectance.
- Darker skin-tone phantoms required increased integration times and camera gain to achieve surface coverage comparable to lighter skin tones.
- Vendor-default settings were not universally applicable, highlighting the importance of site-specific commissioning and optimization.
- The low-cost skin-tone phantoms developed in this study provide a practical quality assurance tool for evaluating and optimizing SGRT performance in diverse patient populations, particularly in resource-constrained radiotherapy centers.

CONCLUSIONS

- ❖ This novel skin-tone phantom study demonstrates that SGRT performance is influenced by skin reflectance characteristics and that vendor-default camera settings may not be optimal for all patient populations.
- ❖ The proposed low-cost, India-specific phantom framework enables skin-tone-based SGRT optimization, promoting equitable and accurate patient positioning while providing a practical quality assurance solution for LMIC radiotherapy centers.

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