Quantitative Optimization of a Lead-Free Hybrid Active Collimator for Enhanced Radiation Protection and Image Fidelity in Mobile Fluoroscopy

Yona Choi, PhD[1]; Kyotae Kim, PhD[2]; Seungwoo Park, PhD[1]
[1]Korea Institute of Radiological and Medical Sciences, Seoul, Rep. of Korea, [2]Gemss Helthcare Inc, Goyang-si, Rep. of Korea

2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

ABSTRACT

Purpose:
In mobile C-arm guided interventions, reducing the radiation dose to the operator's hands and patient's Organ-at-Risk (OAR) is critical. Conventional collimators provide total occlusion, often sacrificing peripheral anatomical context. This study aims to develop and optimize a "see-through" hybrid active collimator using lead-free materials to achieve a balance between significant dose reduction and the maintenance of essential diagnostic visibility.

Methods:
A lead-free composite of Barium Sulfate ($BaSO_4$) and Silicon Dioxide (SiO_2) was fabricated into 1 mm thick sheets. Experimental measurements were performed using a mobile C-arm (XPLUS-35FD, GEMSS Healthcare) at 91 kVp and 4.3 mA with a thorax phantom. Attenuation characteristics (HVL, TVL) and dose rates were measured using a Radcal AGMS-DM+ semiconductor detector. The impact of shielding thickness (1 to 6 mm) on image fidelity was quantitatively evaluated via Modulation Transfer Function (MTF) analysis to identify the clinical threshold for "active" collimation.

Results:
The hybrid material demonstrated an HVL of 0.8 mm and a TVL of 4.0 mm. While the unattenuated dose rate was 17.38 ± 0.2 mGy/min, the material provided effective dose reduction across all tested thicknesses. Analysis of the MTF showed that at an optimal thickness of 3 mm, the system maintained an MTF value of 0.3 at 30% contrast, preserving sufficient image quality to visualize peripheral structures. Beyond 4 mm, the image degradation became clinically unacceptable, rendering the "see-through" capability ineffective. The 2 mm thickness was determined as the optimal point for hybrid collimation, maximizing protection without compromising the surgical field of view.

Conclusion:
The developed $BaSO_4/SiO_2$ hybrid collimator provides a viable solution for OAR protection in fluoroscopy. By maintaining diagnostic fidelity through optimized material thickness, this active collimation system allows for safer interventional procedures. This study establishes the physical and clinical parameters required for implementing lead-free hybrid shielding in real-time imaging environments..

CONTACT

[name] Seungwoo Park
[organization] Korea Institute of Radiological and Medical Sciences
[email] swpark@kirams.re.kr

INTRODUCTION

Mobile C-arm fluoroscopy provides real-time imaging during interventional procedures but exposes both patients and medical staff to ionizing radiation. In particular, the operator's hands may receive relatively high radiation exposure because they are frequently positioned close to the primary beam and scattered radiation field. Although conventional shielding devices can reduce radiation exposure, excessive shielding may obscure anatomical structures and compromise image quality. Therefore, an optimized shielding system must provide sufficient radiation attenuation while maintaining clinically acceptable image visibility.

Objective of this study aimed to develop and quantitatively optimize a novel lead-free hybrid shielding collimator for mobile C-arm fluoroscopy.

The specific objectives were to:

- Evaluate radiation attenuation according to shielding thickness.
- Determine the half-value layer and tenth-value layer of the shielding material.
- Identify the optimal shielding thickness that balances radiation protection and diagnostic image fidelity.

METHODS AND MATERIALS

- Radiation Shielding Materials -

- The shielding material were manufactured by mixing $BaSo_4$, P_bO, $CaCO_3$, and SiO_2 **(Table 1)**
- These materials were formed into square sheets measuring 100 x 100 x 2 (mm^3), and radiation dose and image quality were evaluated by stacking them up to a thickness of 12 mm **(Fig 1)**.

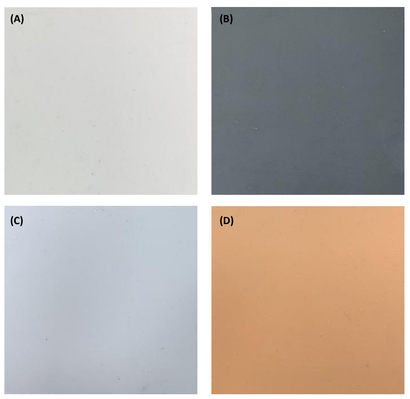

Figure 1. Types of Developed Diagnostic Radiation Shielding Materials

	P_bO (%)	$BaSo_4$ (%)	$CaCo_3$ (%)	SiO_2 (%)	Si Binder
A	-	60	10	20	10
B	-	70	-	20	10
C	50	20	-	20	10
D	40	30	10	10	10

Table 1. Composition ratio of Radiation Shielding Materials

- Lead-Free Hybrid Shielding Material -

The lead-free hybrid shielding material was fabricated using a composite formulation consisting of:
60 wt% barium sulfate ($BaSO_4$)
10 wt% calcium carbonate ($CaCO_3$)
20 wt% silicon dioxide (SiO_2)
10 wt% silicone binder

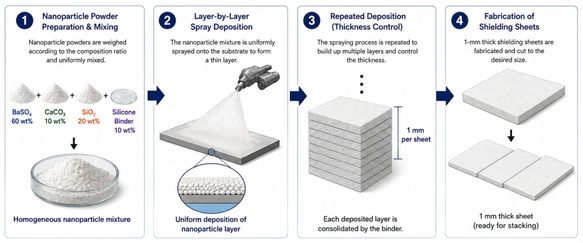

Figure 2. Fabrication Process of Lead-Free Shielding Material

RESULTS

- Radiation Shielding materials Evaluation-

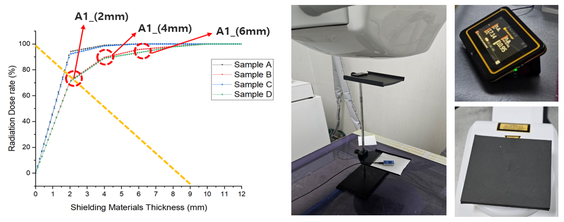

Figure 3. 4 Materials (Lead-free and PbO based material) thickness, with the dose reduction ratio.

- Dose rate at 91kVp and 4.3 mA was measured at 17.38±0.2 mGy/min.
- The analysis results of the area where the radiation dose rate applied was less than 30% indicated that hidden images were confirmed in the thickness of 2.0 mm with Material A.
- HVL of 0.8mm and a TVL of 4.0 mm.

- Mobile Fluoroscopy System -

Fluoroscopic images of a thorax phantom were acquired using the Automatic Brightness System under the following exposure conditions:

- Tube voltage: 91 kVp
- Tube current: 4.3 mA
- Imaging mode: Automatic Brightness System (Using thorax phantom)

For basic image comparison, images were acquired with the Automatic Brightness Stabilizer (ABS) function turned off

Figure 4. Development of Multi-leaf Collimator with Lead-Free hybrid shielding material

- Lead-free materials with Hidden Images -

Thickness-Dependent Image Visibility

- Image visibility was maintained below 2.0 mm but decreased at greater thicknesses due to increased radiation attenuation. At a thickness of 2.0 mm, the material achieved approximately 70% radiation attenuation.

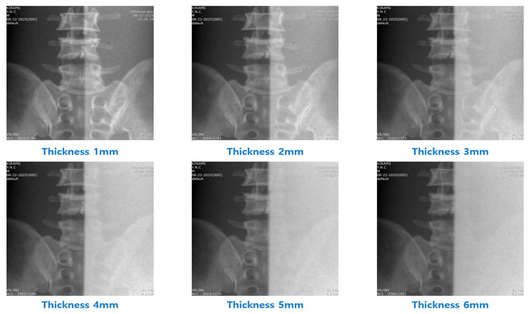

Figure 5. Hidden images using material A (1mm to 6mm thickness)

- Development of Multi-leaf Collimator -

Fabrication of lead-free shielding collimator

- Integration into 10 movable leaves
- Assembly of the multi-leaf collimator
- Adjustment of the shielding field

Figure 6. Development of Multi-leaf Collimator with Lead-Free hybrid shielding material

DISCUSSION & CONCLUSION

1. **Prototype Feasibility**
   The prototype demonstrated the feasibility of a lead-free active collimator that preserves the visibility of structures beneath the shielding material.
2. **System Optimization and Image-Quality Validation**
   The new collimator altered the effective detector pixel size; therefore, pixel-size calibration is currently in progress. Following calibration, quantitative image-quality assessments, including MTF and CTF measurements, will be performed.
3. **3. Conclusion and Future Direction**
   Although further material and structural optimization is required, the developed system showed the potential to reduce radiation exposure while maintaining image visibility. These findings support the potential extension of lead-free active collimation to a wider range of interventional procedures.

REFERENCES

1. Park, H. J. et al. Development and evaluation of modified lead gloves to reduce hand radiation dose during interventional radiological procedures. Nuclear Engineering and Technology (2024).

© Poster Template by Genigraphics® 1.800.790.4001 www.genigraphics.com