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INTERVENTIONAL RADIOLOGY

ORIGINAL ARTICLE

Minimizing radiation exposure in children: the role of spot region of interest imaging in venous access procedures

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PURPOSE

To evaluate the effectiveness of the spot region of interest (ROI) technique in reducing radiation exposure during fluoroscopically guided venous access procedures in pediatric patients.

METHODS

This retrospective study included pediatric patients who underwent central venous access procedures in an interventional radiology unit of a tertiary care center. Data collected included patient demographics, procedure type, target vein, dose area product (DAP), cumulative dose, fluoroscopy time, and the DAP/fluoroscopy time ratio.

RESULTS

A total of 131 patients (mean age: 8 ± 4.91; 48.9% women) were included, of whom 44 (33.6%) underwent procedures using the spot ROI technique. The spot ROI group demonstrated significantly lower DAP and cumulative dose than the non-ROI group (reduction ratios: 63.8% and 67.2%, respectively, $P < 0.001$ for all). When normalized to fluoroscopy time, the DAP/fluoroscopy time ratio was also significantly reduced in the spot ROI group [15.34 (7.18–23.57) vs. 25.17 (18.49–42.03); $P < 0.001$].

CONCLUSION

Spot ROI is an effective and safe technique for reducing radiation exposure during pediatric venous access procedures without compromising procedural success. Given the high radiation sensitivity of pediatric patients and the potential need for repeated interventions in those with chronic conditions, spot ROI represents a valuable tool for dose optimization and aligns with the As Low As Reasonably Achievable (ALARA) principle.

CLINICAL SIGNIFICANCE

Spot ROI-based fluoroscopy significantly reduces radiation exposure in pediatric central venous catheterization without compromising procedural success. This hardware-based dose reduction technique complements the traditional ALARA principle and is particularly valuable for children requiring repeated interventions. These findings support broader clinical adoption and warrant validation in future prospective multicenter studies.

KEYWORDS

Catheter, pediatric, radiation, spot ROI, venous access

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Reducing radiation exposure is essential for ensuring the safety of all interventional radiology procedures, especially in the pediatric population. Pediatric patients are more sensitive to ionizing radiation than adults, and the lifetime risk of radiation-induced malignancy is considerably higher in this population.[1-3] In interventional procedures requiring prolonged fluoroscopy, radiation dose optimization is of paramount importance for patient safety and fulfilling ethical responsibility. This is embodied in the concept of As Low As Reasonably Achievable (ALARA), which emphasizes minimizing radiation dose while maintaining adequate image quality for clinical decision-making.[2] Incorporating the ALARA principle into clinical practice is particularly critical in children, who are more vulnerable to the cumulative effects of repeated imaging and interventions.

Various systems have been introduced to provide either direct or indirect protection against X-ray exposure. Among the earliest of these are beam collimators, which have been used in different designs and configurations since the early days of X-ray imaging to limit radiation dose.[4,5] More recently, the spot region of interest (ROI) function has been developed as an innovative technique to reduce radiation exposure, particularly during neurointerventional procedures.[6]

ROI-based fluoroscopic dose reduction technology delivers full-dose X-rays exclusively to the targeted anatomical region while reducing the dose to surrounding areas by 65%–85% through a motorized attenuation filter.[6] The frosted appearance of the peripheral area allows the operator to visualize the ROI in high resolution while maintaining anatomical orientation.[6,7] Additionally, unlike conventional collimation, the ROI can be moved freely by the table in any X–Y direction.

In pediatric patients, radiation exposure associated with fluoroscopically guided venous access procedures has not been extensively investigated, largely due to the prevailing assumption that the doses involved are relatively low.[8,9]

The present study aims to compare radiation doses in pediatric central venous catheterization procedures performed with and without the spot ROI technique on the same angiography system.

Main points

- Spot region of interest technology provides significant radiation dose reduction during pediatric central venous catheter placement.
- Dose reduction is achieved without compromising procedural success, image quality, or safety.
- This technique offers an effective complement to the As Low As Reasonably Achievable principle and supports safer pediatric interventional radiology practices.

Methods

This retrospective study was conducted at the Interventional Radiology Unit of Akdeniz University Hospital between January 2019 and December 2024. Institutional review board approval was obtained, and the requirement for informed consent was waived due to the retrospective design. Ethical approval for this retrospective study was obtained from the Akdeniz University Ethics Committee (decision number: TBAEK-786; date of approval: 28.08.2025).

The inclusion criteria were as follows: patients aged 0–18 years who underwent venous catheter placement, including temporary or permanent hemodialysis catheters, Hickman and Broviac catheters, and central venous lines (Figure 1). Procedures were performed on an angiography system equipped with spot ROI technology (Alphenix biplane angiographic machine, Canon Medical Systems, Canon, Tochigi, Japan, 2019). Patients with missing dose data were excluded from the study.

For the ROI application, the target anatomical region was aligned with the ROI field on the fluoroscopy monitor (Figure 2). The operator controlled the motorized attenuation filter dynamically via a joystick. The peripheral area appeared frosted but retained low-dose visibility for anatomical orientation. The ROI position could be readjusted as necessary during the procedure.

Procedures were initiated with ultrasound-guided puncture of the vein, followed by ROI-guided fluoroscopy. In cases of vascular variation or procedural difficulty, additional ROI-guided fluoroscopy with contrast injection was used to visualize the venous anatomy before catheter placement.

Statistical analysis

Data collected included patient demographics, procedure type, target vein, dose area product (DAP), cumulative dose, fluoroscopy time, and the DAP/fluoroscopy time ratio. Statistical analyses were performed using IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp., Armonk, NY, USA). The Shapiro–Wilk test was applied to assess the normality of continuous variables. Data not conforming to a normal distribution were reported as median values with interquartile ranges. Comparisons between two groups were conducted using the Mann–Whitney U test. Categorical variables were summarized as counts (n) and percentages (%), with differences between groups evaluated using the chi-square test. A *P* value < 0.05 was considered statistically significant for all analyses.

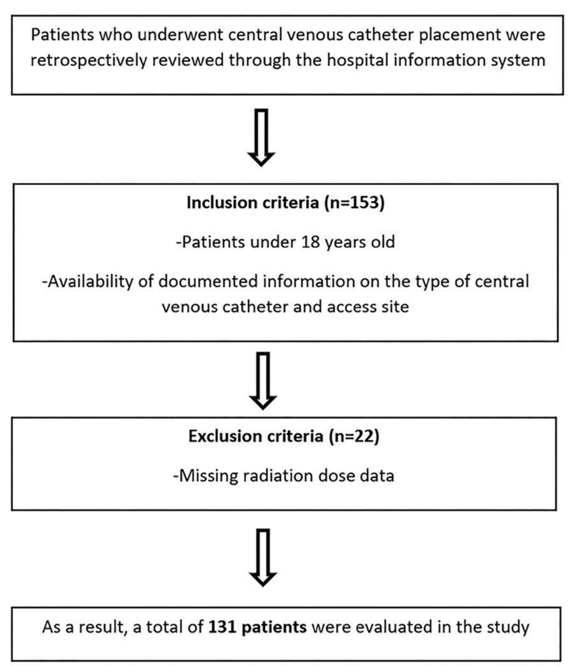

Figure 1. Flowchart illustrating the data collection process with the inclusion and exclusion criteria.

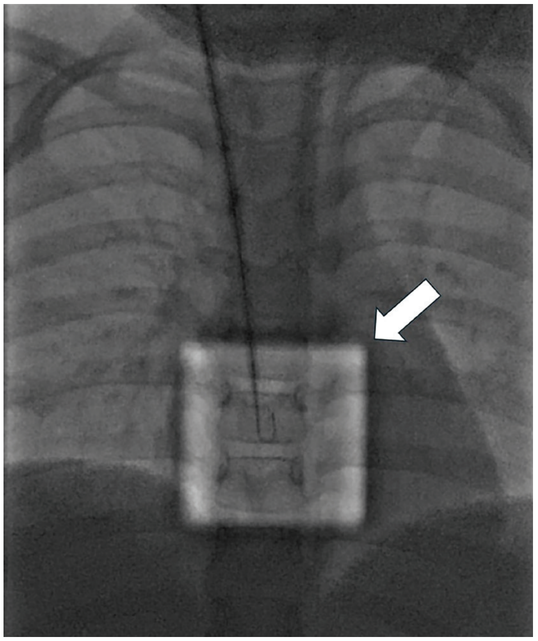

Figure 2. The bright central square (white arrow) represents the area imaged with the standard dose, whereas the darker peripheral zone reflects the application of an additional 0.7 mm copper filter for beam attenuation.

Results

A total of 153 pediatric patients underwent venous catheter placement during the study period. Twenty-two patients were excluded due to missing radiation dose data, leaving 131 patients [mean age: 8 ± 4.91; 48.9% women (n = 64)] for analysis. Of these, 44 (33.6%) procedures were performed using the spot ROI technique, and 87 (66.4%) without it.

There were no significant differences between the groups in terms of age or sex distribution. In both groups, tunneled hemodialysis catheter placement was the most frequent procedure, with the internal jugular vein being the most common access site. In the ROI group, DAP, cumulative dose, and fluoroscopy time were all significantly lower than in the non-ROI group (Table 1). To account for potential differences in fluoroscopy time, the DAP-to-fluoroscopy time ratio was calculated as an indicator of radiation exposure per unit time. This ratio was also significantly reduced in the ROI group compared with the non-ROI group [15.34 (7.18–23.57) vs. 25.17 (18.49–42.03), $P < 0.001$]. Based on median values, the use of spot ROI resulted in reductions of 63.8% in DAP, 67.2% in cumulative dose, and 39% in DAP/fluoroscopy time.

Discussion

Our study findings indicate that the application of spot ROI resulted in a significant reduction in both total and time-normalized radiation doses. The spot ROI-based fluoroscopic dose reduction technique was initially developed for neurointerventional procedures to reduce radiation exposure for both patients and operators. Phantom studies by Borota and Patz[6] demonstrated that ROI provides significantly lower DAP, air kerma, and skin dose than conventional collimation and spot fluoroscopy methods. This is achieved without compromising the visibility of the target anatomy.[6,7]

To our knowledge, no previous studies have specifically evaluated ROI-based dose reduction in pediatric central venous access procedures. Pediatric dose optimization strategies have traditionally relied on the ALARA principle, frame rate reduction, a narrow field of view, or the air gap technique.[2,10] These methods do not incorporate hardware-based ROI filtering mechanisms.

Table 1. Demographic characteristics of the patients and dose-related data of the procedures

	ROI group (n = 44)	Non-ROI group (n = 87)	*P* value
Sex, n (%)			
• Female	20 (45.5)	44 (50.6)	0.580
• Male	24 (54.5)	43 (49.4)	
Age*	7 (5–12)	9 (4.5–14)	0.071
Types of venous access, n (%)			
• Chest wall port	4 (9.1)	0 (0)	< 0.001
• Non-tunneled catheter	4 (9.1)	0 (0)	
• Tunneled catheter	36 (81.8)	87 (100)	
Venous access site, n (%)			
• Jugular	40 (90.9)	86 (98.9)	0.035
• Subclavian	0 (0)	1 (1.1)	
• Femoral	2 (4.5)	0 (0)	
• Transhepatic	2 (4.5)	0 (0)	
Side, n (%)			
• Right	38 (86.4)	68 (78.2)	0.259
• Left	6 (13.6)	19 (21.8)	
Fluoroscopy time (minute)*	1.9 (1.52–2.53)	2.5 (1.99–3.44)	0.003
DAP (cGy·cm^2)*	24.6 (14.36–43.51)	68.03 (38.55–123.44)	< 0.001
Cumulative dose (mGy)*	1.09 (0.61–1.43)	3.32 (2.06–4.95)	< 0.001
DAP/fluoroscopy time*	15.34 (7.18–23.57)	25.17 (18.49–42.03)	< 0.001

*Values are presented as median (interquartile range). ROI, region of interest; DAP, dose area product

Borota and Patz[6] reported that neuroangiographic interventions performed with a biplane angiography system using spot ROI and peripheral-field shielding with a physical attenuation filter resulted in up to a 68% dose reduction. The findings of our pediatric central venous catheter cohort (n = 131) are consistent with these results: in procedures performed with spot ROI, the median DAP was 24.6 cGy·cm^2 compared with 68.03 cGy·cm^2 without ROI, representing an approximate 63.8% reduction ($P < 0.001$); the cumulative dose was 1.09 mGy vs. 3.32 mGy, indicating about a 67.2% reduction ($P < 0.001$); and the DAP/fluoroscopy time ratio, reflecting exposure per unit time, was 15.34 vs. 25.17, approximately 39% lower ($P < 0.001$). Although image quality was not formally scored in this cohort, as reported in the studies by Borota and Patz,[6] the ability to follow surrounding anatomy and the clinical applicability of spot ROI were preserved.

Beyond neurointerventional procedures, this technique has also been applied in percutaneous coronary interventions. Yoshinaga et al.[7] reported that the use of spot ROI markedly decreases radiation dose rates compared with conventional collimation. In their findings, the dose rate with spot ROI was typically reduced to approximately one-third to one-half of that observed without its use. Moreover, this approach may help avoid unintentional dose escalation, which can occur when aggressive collimation triggers automatic dose compensation by the imaging system.

Compared with conventional collimation, the spot ROI functionality provides a more precise and efficient method for radiation dose reduction. Although classical collimation can decrease radiation exposure, it often leads to unintended dose increases due to automatic exposure compensation, and it may also compromise image quality in peripheral regions.[11,12] Spot Fluoroscopy was introduced as an advancement over standard collimation and has been shown to reduce both patient and operator doses while maintaining sufficient image quality. However, it is limited by reduced flexibility and a smaller visual field.[12] In contrast, spot ROI offers a distinct advantage by allowing selective visualization of the target region with continuous dose reduction while preserving peripheral anatomical context.[6] Borota and Patz[6] reported that spot ROI achieves approximately 30%–50% dose reduction compared with conventional collimation, without the drawback of dose compensation effects seen in standard methods. Thus, spot ROI represents a superior evolution of dose-optimization strategies, combining the benefits of spot fluoroscopy with enhanced safety and image fidelity.

The spot ROI technique is applied in neurointerventional and cardiac procedures, where intervention times are typically prolonged. However, its potential benefits in pediatric patients are particularly major, regardless of procedure time. Children are more radiosensitive than adults due to higher cell proliferation rates and longer life expectancy, making any reduction in dose clinically meaningful, especially in those with chronic conditions who require repeated central venous access and are at risk of cumulative radiation exposure due to their increased radiosensitivity.[2] By demonstrating the effectiveness and advantages of spot ROI in this vulnerable group, our study provides a meaningful contribution to the existing literature.

Importantly, ROI use did not adversely affect procedural duration, technical success rates, or image quality, supporting its feasibility and safety in pediatric interventional radiology. This study helps fill a gap in the literature and provides a basis for larger multicenter prospective trials to validate the benefits of spot ROI in this patient population for other interventional radiology procedures.

This study has several limitations. First, its retrospective design may carry inherent risks of selection and referral bias, given that the cohort was derived from a tertiary care institution. Pediatric interventional radiology procedures present specific challenges related to body size, which in this population can range from infants with extremely low birth weight to adolescents and young adults. There was no information regarding the patients' weight and height at the time of the procedure, which may affect the study's dose analysis. Although the case distribution in tertiary centers is typically skewed toward smaller patients, no significant age differences were identified between the groups in this study. Second, the calculated radiation dose estimates are directly relevant only to operators employing comparable equipment, techniques, and training. As our institution is a teaching hospital, a proportion of venous access procedures are performed by radiology residents under faculty supervision. Procedures conducted exclusively by highly experienced operators would likely result in lower radiation exposure. Lastly, the spot ROI technique is currently commercially available only on a single angiography system, which may restrict the generalizability of our findings. Additionally, the implementation of this technology in other centers may be limited by the need for equipment upgrades or associated costs.

In conclusion, the spot ROI-based fluoroscopic dose reduction technique effectively reduces patient radiation exposure during pediatric central venous catheter placement without compromising procedural success. This emerging technology has the potential to enhance both the efficiency and safety of interventional radiology practice. However, its effectiveness and safety should be further validated through prospective multicenter studies.

Footnotes

Conflict of interest disclosure

The authors declared that there is no conflict of interest.

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