A Comparative Study of Patient Radiation Dose between Standard Angiogram and Road-Map Technique in Hemodialysis Patients During Fistuloplasty Using Digital Subtraction Angiography

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Abstract

Objective: To 1) compare the radiation dose received by patients undergoing hemodialysis vascular access angioplasty using Angiogram mode and Road-map mode, 2) evaluate patient radiation dose relative to the International Atomic Energy Agency (IAEA) trigger levels, and 3) identify technical factors influencing dose variation.

Materials and Methods: This retrospective analytical study included 195 patients who underwent hemodialysis vascular access angioplasty at Songklanagarind Hospital between December 2019 and December 2021 (Road-map: 80 patients; Angiogram: 115 patients). Collected parameters included dose area product (DAP), reference point air kerma ($K_{a,r}$), kVp, mAs, fluoroscopy time, frame rate, and number of images. Data were analyzed using an independent t-test and a one-sample t-test.

Results: Mean DAP and $K_{a,r}$ in Road-map mode (0.92 Gy·cm^2 and 3.19 mGy) were significantly higher than Angiogram mode (0.55 Gy·cm^2 and 1.60 mGy) ($p<0.001$). Although Road-map mode utilized shorter fluoroscopy time, its fixed higher frame rate (15 fps vs. 2 fps) resulted in greater radiation exposure. Both techniques remained well below IAEA trigger levels.

Conclusion: Angiogram mode offers an advantage in minimizing radiation dose, whereas Road-map mode may be preferred when rapid image guidance is required.

Keywords: Hemodialysis access intervention; Digital subtraction angiography (DSA); Angiogram mode; Road-map mode; Dose area product (DAP); Reference point air kerma ($K_{a,r}$)

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Chronic kidney disease (CKD) patients who progress to end-stage renal disease (ESRD) require continuous hemodialysis to maintain survival. Studies demonstrate that systematic health behavior promotion, integrated with family and healthcare provider support, significantly reduces complications and improves patients' quality of life[1,2]. The success of hemodialysis relies fundamentally on functional vascular access, specifically arteriovenous fistulas

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What is already known about this topic?

- PTA under DSA is a standard treatment for stenotic vascular access, but it implies radiation exposure risks.
- Trigger levels are established by the IAEA (DAP >300 Gy·cm^2 or $K_{a,r}$ >3 Gy) to prevent deterministic skin effects.
- While technical parameters like frame rate are known to influence radiation dose, there is limited comparative data specifically examining dose differences between Angiogram mode and Road-map mode in fistuloplasty.

What does this study add?

- This study demonstrates that Road-map mode results in significantly higher patient radiation exposure (mean DAP: 0.92 Gy·cm^2) compared to Angiogram mode (mean DAP: 0.55 Gy·cm^2), contrary to conventional assumptions.
- The higher dose in Road-map mode is primarily driven by its fixed, higher frame rate (15 fps) compared to the adjustable, lower frame rate of Angiogram mode (2 fps), despite Road-map requiring shorter fluoroscopy time.
- Both techniques remain well below IAEA safety thresholds, but Angiogram mode is recommended as the preferred technique to minimize radiation exposure in adherence to the ALARA principle.

(AVF) or arteriovenous grafts (AVG)[3]. However, vascular access stenosis is a common complication requiring percutaneous transluminal angioplasty (PTA) or fistuloplasty, which is a safe and effective modality for prolonging vascular access lifespan[4].

While PTA performed under digital subtraction angiography (DSA) guidance enhances procedural precision, it inevitably exposes patients and staff to ionizing radiation. International studies indicate that radiation exposure varies significantly depending on procedural complexity and imaging technique[4]. The International Atomic Energy Agency (IAEA) has established trigger levels to prevent radiation risks (DAP >300 Gy·cm² or reference point air kerma ($K_{a,r}$) >3 Gy)[5].

At Songklanagarind Hospital, many hemodialysis patients require repeated fistuloplasty procedures, increasing cumulative radiation exposure risk. Currently, there is uncertainty regarding optimal imaging mode selection: Road-map mode versus Angiogram mode. This study aims to compare radiation doses between Angiogram and Road-map modes during fistuloplasty procedures, providing data to support the reduction of unnecessary radiation exposure in adherence to the ALARA (as low as reasonably achievable) principle. Specific objectives are to compare patient radiation doses between the two modes, evaluate compliance with IAEA trigger levels, and analyze technical factors, specifically frame rate settings, associated with observed differences in radiation exposure.

Materials and Methods

Design and Setting

Retrospective analytical study at the Minimally Invasive Surgical-Interventional Radiology Center, Songklanagarind Hospital, Thailand, between December 1, 2019, and December 31, 2021.

Participants

Inclusion criteria: patients ≥15 years undergoing fistuloplasty using either Angiogram or Road-map as primary imaging mode. Exclusion criteria: incomplete records or thoracic central venous angioplasty. Sample: 195 procedures (Road-map: 80 patients; Angiogram: 115 patients). This study analyzed these 195 consecutive procedures as individual units of analysis. The dataset reflects standard clinical practice, including repeated interventions on the same individuals to manage recurring vascular access complications in hemodialysis patients.

Sample Size Calculation

Calculated using the two-sample difference of means formula[6]: significance level (α)=0.05 ($Z_{\alpha/2}$=1.96), statistical power=90% (β=0.10, Z_{β}=1.28); effect size Δ/σ=0.5.

Imaging Systems and Data Sources

Procedures utilized a calibrated DSA system with Radimetrics dose-tracking integration. Retrieved variables: DAP (Gy·cm²), $K_{a,r}$ (mGy), kVp, mAs, fluoroscopy time, frame rate, and total image count verified via the picture archiving and communication system (PACS) and case record forms.

Outcomes and Statistical Analysis

Primary outcomes: DAP and $K_{a,r}$. Secondary parameters: kVp, mAs, fluoroscopy time, frame rate, image count. Data were summarized as mean ± standard deviation (SD). We used independent t-tests for between-group comparisons and one-sample t-tests to compare observed means with IAEA thresholds; significance was defined as a p-value less than 0.05.

Ethics Approval

Approved by the Human Research Ethics Committee, Faculty of Medicine, Prince of Songkla University (REC.65-111-7-7). Informed consent was waived due to the retrospective nature and de-identification.

Results

A total of 195 hemodialysis patients undergoing fistuloplasty between December 2019 and December 2021 were retrospectively divided into Road-map (80 patients) and standard Angiogram (115 patients) groups. Baseline characteristics were well-matched with no significant differences between the Road-map and Angiogram groups (all p>0.05). Specifically, there were no differences in male proportion (61.2% vs. 52.2%, p=0.215), mean age (67.6±12.3 vs. 68.7±11.5 years, p=0.532), weight (63.4±12.5 vs. 65.2±13.8 kg, p=0.341), or height (165.2±8.7 vs. 163.5±9.2 cm, p=0.189). Additionally, vascular access types, including arteriovenous fistula (62 vs. 84 cases, p=0.547) and AVG (15 vs. 31 cases, p=0.184), were comparable between the two groups, ensuring homogeneity for comparing radiation exposures.

Statistically significant differences in radiation doses were observed between the two groups (p<0.001). The Road-map group received a higher radiation dose, with a mean DAP of 0.92±0.61 Gy·cm² (median 0.81, IQR 0.40-1.31, range 0.18-3.87) and

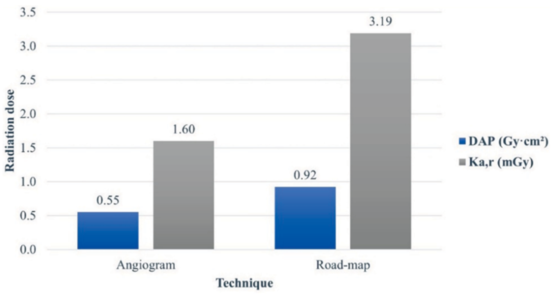

Figure 1. Comparison of mean DAP and Ka,r between Angiogram and Road-map modes.

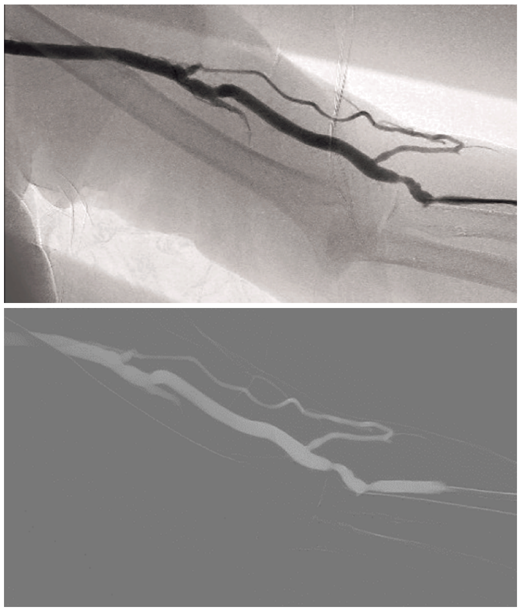

Figure 2. Comparison of imaging techniques: (A) standard angiogram mode and (B) road-map mode during the procedure.

a mean $K_{a,r}$ of 3.19±1.80 mGy (median 2.69, IQR 1.92-4.12, range 0.56-9.82). In comparison, the Angiogram group showed a mean DAP of 0.55±0.37 Gy·cm² (median 0.48, IQR 0.32-0.70, range 0.05-2.43) and a mean $K_{a,r}$ of 1.60±1.03 mGy (median 1.41, IQR 0.97-1.94, range 0.14-8.27), as shown in Figure 1. Furthermore, although the Road-map mode utilized a shorter median fluoroscopy time, it was associated with a higher total radiation burden per procedure.

Representative images of the standard angiogram and road-map technique are displayed in Figure 2, illustrating the different visual guidance used during the procedures.

Safety in Relation to Trigger Levels

The mean DAP and $K_{a,r}$ for both imaging techniques were significantly lower than established IAEA trigger levels (p<0.001), suggesting patients remained within a safe exposure range and were not at risk of deterministic skin effects, even with repeated procedures.

Influence of Technical Parameters

Frame rate was the primary factor affecting radiation dose. Angiogram mode operated at approximately 2 fps, whereas Road-map mode operated at a fixed 15 fps, which could not be adjusted. Despite shorter fluoroscopy time, the higher frame rate in Road-map mode led to greater total radiation dose, highlighting the importance of technical parameter selection in dose optimization.

Discussion

Radiation Dose Differences

The findings contradicted the initial hypothesis. Generally, Angiogram mode yields higher radiation doses compared to standard fluoroscopy[7]. However, Road-map mode produced significantly higher radiation doses than Angiogram mode (p<0.001). The mean DAP for Road-map mode reached 0.92 Gy·cm² compared to 0.55 Gy·cm² in Angiogram mode, while the mean $K_{a,r}$ for Road-map mode was 3.19 mGy versus 1.60 mGy for Angiogram mode. These disparities occurred despite Road-map mode utilizing shorter fluoroscopy duration (18.58 vs. 35.85 seconds). This aligns with Bor et al.[8], who established that DAP and $K_{a,r}$ are precise indicators for effective dose assessment. Specifically, DAP is used for estimating stochastic risk, whereas $K_{a,r}$ is a crucial indicator for estimating tissue reaction risks (deterministic risk).

Although $K_{a,r}$ is widely used to estimate tissue reaction risks, it represents an air kerma measurement at the reference point (located 15 cm from the isocenter toward the X-ray tube). Because this reference point moves with the gantry and does not account for patient backscatter radiation (which typically adds 30% to 40% to the measured $K_{a,r}$), accurate peak skin dose estimation requires further consideration of gantry motion, patient size, and patient positioning relative to the gantry. In this study, however, all maximum $K_{a,r}$ values remained below 10 mGy, which is significantly lower than the 3 Gy (3,000 mGy) safety trigger level. Therefore, even when accounting for potential backscatter factors, the maximum skin doses in our cohort clearly remained well below the threshold for deterministic effects.

Influence of Technical Parameters and Imaging Protocols

Analysis identified imaging settings as the primary determinants for the observed dose discrepancy. In our institutional protocol, the angiogram mode utilized an adjustable acquisition frame rate set at 2 fps, while the road-map mode operated at a fixed, non-adjustable frame rate of 15 fps. Although the road-map mode utilized a continuous overlay technique to guide intervention, its higher fixed frame rate significantly contributed to the increased cumulative dose. These findings align with Gailloud[9] and Ferraz et al.[10], who emphasized that higher frame rates substantially increase radiation exposure. Consequently, this highlights a critical clinical implication: the selection of imaging techniques must be informed by specific technical parameters rather than conventional assumptions.

Safety in Relation to IAEA Trigger Levels

Radiation exposure from both techniques remained significantly below IAEA trigger levels. These findings are consistent with Beathard et al.[4], who reported mean kerma area product (KAP) values for fistula angioplasty well below safety standards. Our results are further supported by Heye et al.[11] and Storm et al.[12], confirming that dialysis access interventions do not pose a risk of deterministic skin injury, even with repeated procedures. The low dose levels observed are attributed to systematic implementation of "Low-dose" protocols, developed through collaboration between radiologists and application specialists. This practice adheres to the ALARA principle[13] and mirrors findings of Livingstone et al.[14], which demonstrated that low-dose protocols can reduce radiation by up to 50% while maintaining diagnostic image quality.

Limitation

This retrospective study limits the ability to control for all potential confounding variables. The selection of imaging mode was determined by clinical judgment rather than randomization, potentially introducing selection bias. This single-center study using specific equipment may not be fully generalizable to other facilities with different DSA systems or protocols.

Recommendations for Clinical Practice

Angiogram mode should be considered the preferred imaging technique for routine fistuloplasty to minimize radiation exposure. Road-map mode may be used when rapid or continuous image guidance is needed, but its use should be carefully justified. Training for interventional teams should emphasize the impact of frame rate on radiation dose and promote consistent application of the ALARA principle.

Recommendations for Future Research

Future studies should employ prospective designs to control technical variables such as frame rate adjustment or integration of dedicated low-dose imaging protocols to directly evaluate their effects on radiation dose and image quality. Additionally, further research should include assessments of radiation exposure to healthcare personnel and long-term follow-up of patients undergoing repeated procedures to better understand cumulative radiation risk and support the development of radiation safety policies at institutional and national levels.

Conclusion

This study demonstrated that Angiogram mode during hemodialysis access angioplasty resulted in significantly lower patient radiation dose compared with Road-map mode. Although Road-map mode required shorter fluoroscopy time, its substantially higher frame rate contributed to increased cumulative radiation dose. Nonetheless, radiation doses from both techniques remained well below IAEA trigger levels, indicating safe procedures within acceptable exposure limits.

Authors Contributions

All listed authors have made substantial contributions to this research: AS: Conceptualization, methodology, investigation, formal analysis, and writing-original draft. WU: Investigation, resources, and writing-review & editing. CF: Investigation and resources. JC: Supervision, validation, and writing-review & editing. KH: supervision, validation, and writing–review & editing. All authors have reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

Clinical Trial Registration

This study is a retrospective analytical study and is not a clinical trial; therefore, clinical trial registration is not applicable.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The datasets generated and analyzed during this study are not publicly available due to patient privacy and institutional data governance requirements, but are available from the corresponding author upon reasonable request and with approval from the Human Research Ethics Committee, Faculty of Medicine, Prince of Songkla University.

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Ethics Approval and Consent to Participate

This study was approved by the Human Research Ethics Committee, Faculty of Medicine, Prince of Songkla University (Approval No. REC.65-111-7-7). Informed consent was waived by the ethics committee due to the retrospective nature of the study and complete de-identification of all patient data.

Use of Artificial Intelligence

Artificial Intelligence (AI) tools, specifically Gemini (Google), were used for language editing and translation support to improve the readability and grammatical accuracy of this manuscript. The authors have reviewed and edited the content generated by the AI and take full responsibility for the integrity and accuracy of the final manuscript.

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