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Original Article

Radiation Dose Reduction as an Objective Marker of Procedural Maturation During Early Neurointerventional Fellowship Training: A Six-Month Longitudinal Study

Pinto Desti Ramadhoni[1], Lenny Octavinawaty[1], Diah Andini[1]✉, Budiman Juniwijaya[1], Natasya Wanda Yuniza[1], Nurdiansyah[1], Dewie Susan[1], Ardy Oktaviandi[1]

[1] Department of Neurology, Faculty of Medicine, Sriwijaya University; Mohammad Hoesin General Hospital, Palembang, Indonesia

Corresponding Author:
Diah Andini
Department of Neurology, Faculty of Medicine, Sriwijaya University; Mohammad Hoesin General Hospital, Palembang, Indonesia
Email: diahandinidr@gmail.com

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Introduction: Radiation safety is a fundamental component of neurointerventional practice and competency-based fellowship training. While fluoroscopy time has traditionally been used as a surrogate marker of procedural efficiency, it may not accurately reflect total radiation exposure. Dose-related metrics may better represent technical maturation and radiation-conscious procedural behavior during fellowship progression. **Objective:** This study compared fluoroscopy time and radiation dose to characterize the early learning curve of neurointerventional fellowship training. **Method:** This retrospective observational study analyzed 108 consecutive DSA-based brain angiograms performed during the first six months of a supervised fellowship. Chronological case-sequence linear regression was employed to evaluate longitudinal changes in radiation dose and fluoroscopy time. **Result:** The mean fluoroscopic radiation dose decreased by 42.8%, dropping from 170.17 mGy in month 1 to 97.36 mGy in month 6. Linear regression revealed a significant negative association between case sequence and radiation dose (B = -0.468 mGy/case; p = 0.012; R^2 = 0.058). In contrast, fluoroscopy time showed only modest fluctuations and no significant linear association (p = 0.780). **Conclusion:** During early fellowship training, fluoroscopic radiation dose demonstrates a clearer temporal trend than fluoroscopy time, suggesting it is a more informative marker of procedural maturation. However, the low explanatory power and the absence of adjustment for procedural complexity require cautious interpretation. These findings warrant further research incorporating complexity-adjusted designs to better define technical maturation.

Keywords: Fellowship, Fluoroscopy time, Neurointervention, Procedural learning curve, Radiation dose

Highlights
- Radiation dose declined progressively during early neurointerventional training.
- Radiation dose has a clearer temporal trend than fluoroscopy time in early training.

Introduction

Digital subtraction angiography (DSA) remains the gold standard for the detailed evaluation of cerebrovascular anatomy and continues to play a central role in neurointerventional practice. Despite the increasing use of non-invasive vascular imaging, DSA still offers superior spatial and temporal resolution for diagnosing intracranial vascular disease and guiding interventions. However, DSA-based procedures expose both patients and operators to

Ionizing radiation makes radiation safety a critical component of procedural competency and quality assurance in modern neurointervention.[1,2,3]

Radiation exposure during neurointerventional procedures is influenced by multiple factors beyond procedural duration, including fluoroscopy settings, pulse rate, frame rate, collimation, magnification, angiographic acquisition frequency, projection selection, and operator technique. Consequently, fluoroscopy time alone may not accurately reflect the true radiation burden of a procedure. Direct dose-related parameters, such as cumulative air kerma and dose-area product, have been shown to provide a more reliable representation of radiation exposure. [4,5,6]

In the context of neurointerventional fellowship training, procedural competence extends beyond technical catheterization skills to include diagnostic interpretation, interventional skill development, and radiation-conscious procedural behavior. While procedural volume remains a traditional benchmark of fellowship progression, contemporary competency frameworks emphasize multidimensional assessment, including procedural safety and efficiency.[7,8]

Several studies have evaluated learning curves in cerebral angiography and neurointerventional training, particularly the relationship between operator experience, fluoroscopy time, and radiation exposure.[9,10,11] However, these findings remain heterogeneous, with variability influenced by study design, procedural complexity, institutional protocols, and technological factors.

There are many studies on operator learning curves, but most were derived from high-resource or simulation-based environments; few have examined real-world longitudinal training data in developing healthcare systems, particularly in settings with variable procedural complexity and resource availability.[11,12] Moreover, the relative utility of radiation dose compared with fluoroscopy time as an indicator of early procedural maturation remains incompletely characterized across different training contexts.

In Indonesia, the national neurointerventional fellowship program under the Indonesian Ministry of Health has been established to strengthen subspecialty expertise and referral-based neurovascular services.[13] However, objective procedural indicators reflecting both technical maturation and radiation safety within this context remain underreported. Therefore, we conducted a longitudinal cohort analysis using chronological case-sequence modeling to evaluate temporal changes in fluoroscopy time and radiation dose during the early phase of neurointerventional fellowship training and to explore their potential roles as markers of procedural progression.

Objective

To characterize the early learning curve of neurointerventional fellowship training by analyzing longitudinal changes in fluoroscopic radiation dose and fluoroscopy time, and to explore whether radiation dose may serve as a more informative marker of procedural maturation than fluoroscopy time.

Method

This retrospective longitudinal observational study was conducted at the neurointerventional fellowship training program at Mohammad Hoesin General Hospital, Palembang, Indonesia. All procedures were performed using a Philips Allura Xper FD20 single-plane angiography system. Angiographic acquisitions were routinely obtained at a frame rate of 2 frames per second (2 fps). Default fluoroscopy parameters, including pulse rate, tube voltage, and filtration, were standardized according to institutional protocol throughout the study period. The individual angiographic procedure served as the unit of analysis.

A total of 108 consecutive eligible DSA-based brain angiographic procedures performed during the first six months of supervised training were included. Procedures were included if all intended target-vessel angiography was successfully completed, diagnostic image quality was adequate for expert interpretation, and complete fluoroscopy time and radiation dose records were available. Procedures were excluded if they involved an incomplete angiographic examination, failure to catheterize or evaluate the intended target vessels, non-diagnostic or technically inadequate image acquisition, predominant completion by the supervising consultant, missing fluoroscopy time or radiation dose data, or technical failure of radiation recording systems. The number of excluded cases during the study period was limited and not systematically stratified by month; therefore, the potential for differential exclusion bias across training periods cannot be entirely excluded.

The cohort consisted of procedures primarily performed by two neurointerventional fellowship trainees under the direct supervision of two consultant neurointerventional supervisors. Supervisors were present throughout the procedures to ensure patient safety and procedural appropriateness, but procedures predominantly completed by the supervising consultant were excluded from the analysis.

For each eligible procedure, the following variables were collected: age, sex, fellowship month (1–6), chronological case number, fluoroscopy time (minutes), and fluoroscopic radiation dose. The latter was recorded as cumulative reference air kerma at the interventional reference point (mGy). Reference air kerma was chosen as the primary dose-related metric because the angiography

system consistently recorded it, and it is a standardized indicator of patient radiation exposure during fluoroscopically guided procedures. The dose-area product provides complementary data on the total radiation burden, although reference air kerma was prioritized because it was consistently available across the cohort.

Baseline cohort characteristics and monthly fluoroscopy parameters were summarized descriptively. Continuous variables were presented as mean ± standard deviation and median (minimum–maximum), while categorical variables were reported as frequencies and percentages. Monthly patterns in fluoroscopy time and fluoroscopic radiation dose were further visualized using line graphs. Separate regression models were used to assess the association between chronological case number and fluoroscopic radiation dose or fluoroscopy time. Learning curves analysis was performed using chronological case-sequence linear regression. Regression coefficients (B), p-values, and coefficients of determination (R^2) were reported. Statistical significance was defined as $p < 0.05$. Due to the retrospective nature of the study and the absence of systematically recorded procedural complexity variables (such as number of vessels studied, vascular anatomy, access route, and angiographic acquisition count), multivariable adjustment was not performed.

Result

Baseline characteristics

A total of 108 procedures were included in the analysis. The study population had a mean age of 51.78 ± 14.05 years, with a median age of 54.00 years (range, 20–79 years). Most procedures were performed on patients aged <60 years (71 cases; 65.74%), whereas 37 cases (34.26%) were performed in patients aged ≥60 years. The sex distribution was relatively balanced, with 52 male patients (48.15%) and 56 female patients (51.85%). The distribution of eligible procedures across the six-month fellowship period was as follows: 16 procedures (14.81%) in month 1, 24 (22.22%) in month 2, 26 (24.07%) in month 3, 18 (16.67%) in month 4, and 12 procedures (11.11%) in both months 5 and 6 (Table 1).

Fluoroscopy time

Overall, the mean fluoroscopy time was 13.39 ± 6.11 minutes, with a median of 12.50 minutes (range, 4.12–46.13 minutes). Across the six-month training period, mean fluoroscopy time showed modest variation, ranging from 12.30 ± 5.93 minutes in month 3 to 14.17 ± 9.84 minutes in month 1. Monthly mean values were 14.17, 13.88, 12.30, 14.37, 13.15, and 12.61 minutes for months 1 through 6, respectively (Table 2).

Fluoroscopy radiation dose

The average fluoroscopic radiation dose was 127.86 ± 60.79 mGy, with a median of 119.00 mGy (range, 30.35–468.87 mGy) (Table 2). Over six months, the mean fluoroscopic dose decreased from 170.17 ± 112.12 mGy in month 1 to 97.36 ± 34.68 mGy in month 6. Intermediate monthly mean values were 129.77, 123.87, 123.29, and 113.68 mGy in months 2 through 5, respectively.

Table 1. Baseline characteristics of eligible fellowship brain DSA procedures

Variable	n (%)
Age (years)	
Mean±SD	51.78±14.05
Median (min-max)	54 (20-79)
Age group	
<60 years	71 (65.74)
≥60 years	37 (34.26)
Gender	
Male	52 (48.15)
Female	56 (51.85)
Time period	
Month 1	16 (14.81)
Month 2	24 (22.22)
Month 3	26 (24.07)
Month 4	18 (16.67)
Month 5	12 (11.11)
Month 6	12 (11.11)

Table 2. Monthly fluoroscopy parameters of eligible fellowship brain DSA procedures

Variable	Mean±SD	Median (min-max)
Fluoroscopy time (min)	13.39±6.11	12.50 (4.12-46.13)
Month 1	14.17±9.84	11.30 (6.39-46.13)
Month 2	13.88±5.79	12.79 (6.21-30.20)
Month 3	12.30±5.93	10.06 (4.12-22.10)
Month 4	14.37±3.84	14.58 (7.05-19.31)
Month 5	13.15±4.73	12.84 (5.28-20.54)
Month 6	12.61±5.47	13.19 (4.29-20.15)
Fluoroscopic dose (mGy)		
Month 1	170.17±112.12	139.65 (47.77-468.87)
Month 2	129.77±34.67	120.40 (80.69-205.10)
Month 3	123.87±56.69	123.14 (38.54-227.90)
Month 4	123.29±38.77	135.88 (36.46-173.89)
Month 5	113.68±39.33	99.48 (76.08-182.51)
Month 6	97.36±34.68	90.62 (30.35-147.28)

Monthly descriptive trends

Fluoroscopy time showed a modest and fluctuating pattern over time (Figure 1). Mean fluoroscopy time decreased slightly from 14.17 minutes in month 1 to 12.61 minutes in month 6, corresponding to a relative reduction of approximately 11.0%, with intermediate variations observed across months.

In contrast, fluoroscopic radiation dose demonstrated an overall downward trend over the six-month observation period (Figure 2). Mean fluoroscopic dose decreased from 170.17 mGy in month 1 to 97.36 mGy in month 6, corresponding to a relative reduction of approximately 42.8%.

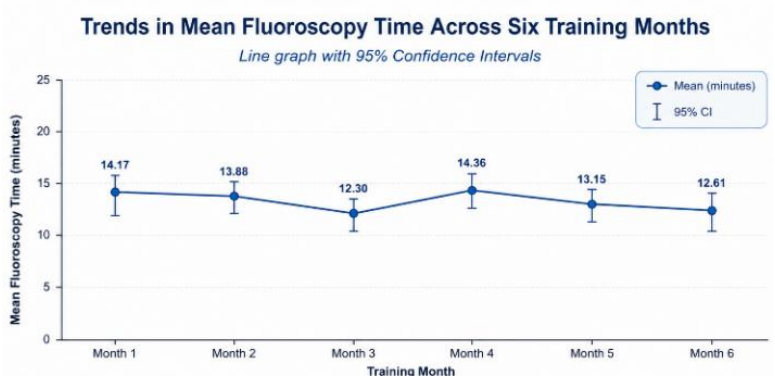

Figure 1. Monthly trend of mean fluoroscopy time across six consecutive training months. The line graph illustrates the mean fluoroscopy time (minutes) recorded for each training month (Months 1–6). The x-axis represents the training month, while the y-axis represents mean fluoroscopy time in minutes. Data points indicate the monthly mean values, and the vertical error bars represent the 95% confidence intervals (95% CI), demonstrating the variability of fluoroscopy time measurements within each month. A fluctuating but overall decreasing trend in fluoroscopy time was observed over the six-month training period

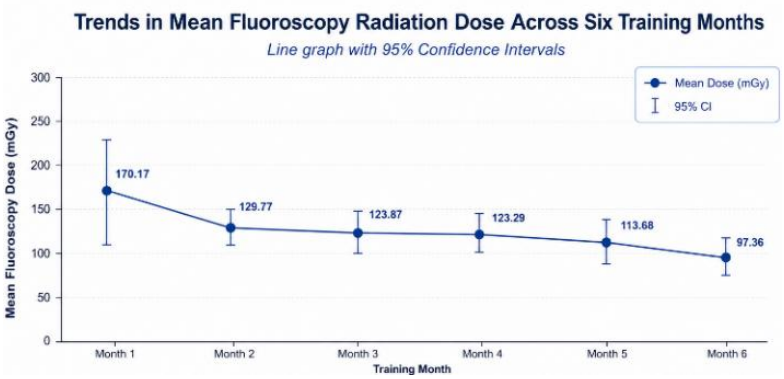

Figure 2. Monthly trend of mean fluoroscopy radiation dose across six consecutive training months. The line graph illustrates the mean fluoroscopy radiation dose (mGy) recorded for each training month (months 1–6). The x-axis represents the training month, while the y-axis represents the mean fluoroscopy radiation dose in milligray (mGy). Data points indicate the monthly mean values, and the vertical error bars represent the 95% confidence intervals (95% CI), reflecting the variability of radiation dose measurements within each month. An overall decreasing trend in fluoroscopy radiation dose was observed over the six-month training period, suggesting progressive improvement in radiation optimization and procedural efficiency during fellowship training.

Overall, these findings suggest that radiation dose improved more consistently than fluoroscopy time during the early phase of fellowship training. This pattern may reflect increasing awareness of radiation optimization and more efficient fluoroscopic imaging practices, despite variability in procedural duration.

Chronological regression analysis

Chronological case-sequence linear regression demonstrated a significant negative association between chronological case number and fluoroscopic radiation dose ($B = -0.468$ mGy/case; $p = 0.012$; $R^2 = 0.058$), indicating a progressive reduction in radiation exposure with increasing procedural experience. In contrast, fluoroscopy time showed no significant linear association with chronological case number ($B = -0.005$ min/case; $p = 0.780$; $R^2 = 0.001$), suggesting that procedural duration did not exhibit a clear learning-related improvement across the observation period.

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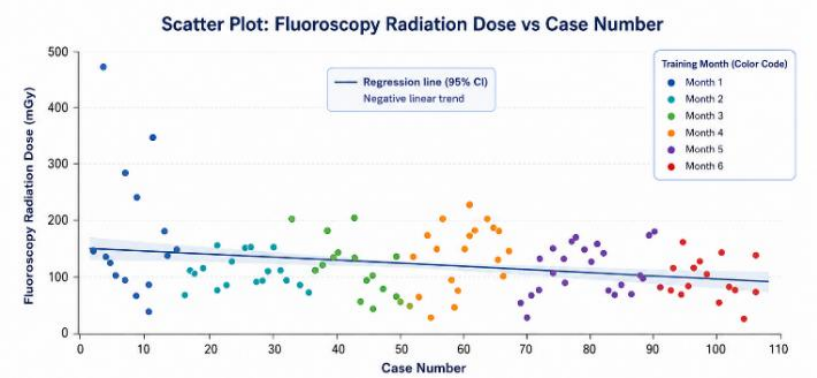

Figure 3. Scatter plot of chronological case number versus fluoroscopic radiation dose. The x-axis represents the cumulative case number, while the y-axis represents fluoroscopic radiation dose measured in milligray (mGy). Each data point corresponds to an individual angiographic procedure and is color-coded according to training month (months 1–6) to illustrate temporal procedural trends throughout the fellowship period. The fitted regression line demonstrates a negative linear association between cumulative case number and fluoroscopic radiation dose, indicating a gradual reduction in radiation exposure with increasing procedural experience. The shaded area surrounding the regression line represents the 95% confidence interval (95% CI). Linear regression analysis showed a significant negative trend (B = −0.468, p = 0.012, R^2 = 0.058).

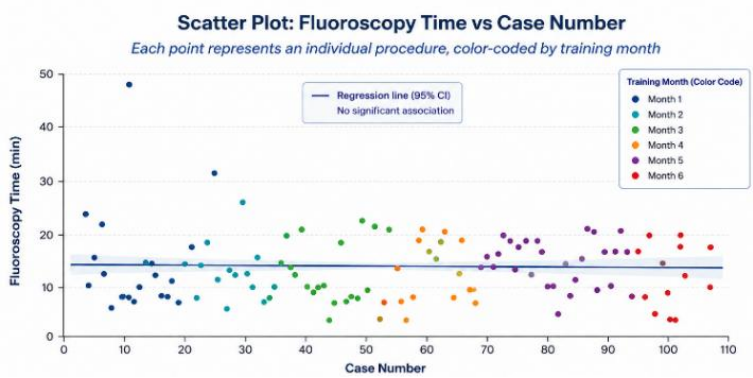

Figure 4. Scatter plot of chronological case number versus fluoroscopy time. The x-axis represents the cumulative number of cases, while the y-axis represents fluoroscopy time, measured in minutes. Each data point corresponds to an individual angiographic procedure and is color-coded according to training month (Months 1–6) to facilitate visualization of temporal procedural trends during fellowship training. The fitted regression line demonstrates no significant association between cumulative case number and fluoroscopy time, indicating that procedural duration did not consistently decrease with increasing operator experience. The shaded area surrounding the regression line represents the 95% confidence interval (95% CI). Linear regression analysis showed no statistically significant linear relationship (B = −0.005, p = 0.780, R^2 = 0.001).

Scatter plot showing the relationship between chronological case number and fluoroscopic radiation dose, demonstrating a significant negative linear trend with cumulative procedural experience (Figure 3). Scatter plot showing the relationship between chronological case number and fluoroscopy time, demonstrating no significant linear trend across the training period (Figure 4).

Discussion

This study demonstrated a progressive reduction in fluoroscopic radiation dose during the first six months of neurointerventional fellowship training, whereas fluoroscopy time showed a more modest and fluctuating pattern. These findings suggest that radiation dose may demonstrate a clearer temporal trend than fluoroscopy time during the early phase of training. However, the observed association between chronological case sequence and fluoroscopic radiation dose had a relatively low coefficient of determination (R^2 = 0.058), indicating that only a small proportion of the variability in radiation exposure is explained by procedural sequence alone. Similarly, fluoroscopy time demonstrated an even lower explanatory value (R^2 = 0.001). These findings suggest that additional factors beyond operator experience, particularly procedural complexity, vascular anatomy, access route, and technical variability, likely contribute substantially to both radiation dose and fluoroscopy time variation.

Radiation exposure in fluoroscopically guided procedures is influenced by multiple variables, including pulse rate, frame rate, collimation, magnification, projection angles, and the number of image acquisitions. Therefore, fluoroscopy time represents only one component of radiation exposure and may underestimate or misrepresent the true radiation burden. This explains why, in the present study, radiation dose showed a clearer temporal pattern than fluoroscopy time.[11,12,14,15]

Previous studies have demonstrated that greater operator experience is associated with reductions in

fluoroscopy time and radiation exposure, supporting the concept of a procedural learning curve in cerebral angiography.[10] In addition, structured and simulation-based training approaches have been shown to improve procedural performance and radiation safety.[11,12] Advances in imaging technology and the implementation of dose-optimization strategies have also been shown to significantly reduce radiation exposure without compromising image quality or procedural outcomes, including the use of high-kV techniques and optimized mask imaging.[16,17] However, prior studies also emphasize that learning curves in neurointervention are multifactorial and strongly influenced by procedural complexity, institutional protocols, and technological factors.[11,18]

Interestingly, fluoroscopy time in this study showed a non-linear pattern rather than a continuous decline. This finding is consistent with real-world training conditions, where procedural complexity, case variability, and increasing trainee autonomy may influence procedural duration. Multicenter and real-world studies have similarly demonstrated substantial variability in fluoroscopy time and radiation dose across diagnostic cerebral angiography procedures. Therefore, fluctuations in fluoroscopy time should not necessarily be interpreted as reduced procedural performance.[12,19]

The absolute radiation dose observed in this study was lower than that reported in some multicenter benchmarks.[12] This discrepancy may be explained by differences in case selection, as the present study primarily included diagnostic cerebral angiography procedures, as well as variations in angiography system configuration and institutional dose-optimization protocols. These factors may limit direct comparability with previously reported reference levels.[20,21,22]

From an educational perspective, the observed reduction in radiation dose over time may reflect increased operator awareness of radiation-optimization strategies and improved fluoroscopic efficiency during early training. However, given the absence of adjustment for procedural complexity and other confounding variables, these findings should be interpreted as descriptive temporal trends rather than definitive evidence of a causal learning effect.[7,23,24]

From a broader training perspective, fellowship evaluation should not rely solely on procedural volume or case completion. While these conventional metrics remain important, they may not fully capture the development of procedural quality and safety. Objective indicators, particularly those related to radiation exposure, may provide additional insight into procedural performance, although their role as independent markers of competency progression requires further validation.[8,25,26]

This study also has implications for structured training programs such as the neurointerventional fellowship program under the Indonesian Ministry of Health.[13] Monitoring radiation dose trends over time may provide a practical and quantifiable measure of trainee progression and procedural quality; however, such interpretation should be made cautiously, given the influence of procedural variability and unmeasured confounding factors.

Several limitations should be acknowledged. First, this was a single-center retrospective study with a relatively small sample size and unequal distribution of procedures across months. Second, the analysis did not account for potential confounding factors such as case complexity, vascular anatomy, access route, and angiographic acquisition count, which limit causal interpretation of radiation dose reduction. Third, although the angiography system model was identified, variability in procedural parameters may still have influenced the absolute radiation dose values observed in this study. Fourth, potential differential exclusion bias cannot be fully ruled out, as excluded cases were not systematically stratified across training months; therefore, the observed reduction in radiation dose may partially reflect changes in case mix rather than a true procedural improvement. Finally, the low coefficient of determination indicates that additional unmeasured factors contribute to variability in both radiation dose and fluoroscopy time.

Nevertheless, this study provides real-world insight into radiation dose trends during the early phase of neurointerventional fellowship training in a developing healthcare setting. These findings suggest a potential role for radiation dose monitoring in training evaluation frameworks, while emphasizing the need for future studies that incorporate prospective, multicenter, and complexity-adjusted designs to better clarify the relationship between procedural experience and radiation optimization.

Conclusion

Fluoroscopic radiation dose demonstrated a clearer temporal trend than fluoroscopy time during the early phase of neurointerventional fellowship training. A progressive reduction in radiation dose was observed over the six-month training period, whereas fluoroscopy time showed a more variable, non-linear pattern.

However, the low coefficient of determination and the lack of adjustment for procedural complexity indicate that the chronological sequence of cases explained only a limited proportion of the variability in radiation exposure. Therefore, these findings should be interpreted as descriptive temporal trends rather than definitive evidence of a causal learning effect or competency progression.

Further prospective, multicenter, and complexity-adjusted studies are warranted to better clarify the relationship between procedural experience, radiation optimization, and fellowship training outcomes.

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Conflict of Interest

The authors declare that an author of this manuscript is a member of the journal's editorial team. However, the author was not involved in the peer-review process, editorial evaluation, or decision-making for this publication. To ensure an unbiased and objective procedure, all editorial processes from submission to publication were conducted independently, without the author's input or authority.

Ethic consideration

This study was approved by the Ethics Committee of RS Dr. Mohammad Hoesin Palembang with protocol number 04.03/D.XVIII.06.08/ETIK/257/2025.

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Author contribution

Pinto Desti Ramadhoni: Conceptualization, Methodology, Data curation, Formal analysis, Investigation, Writing–original draft. **Lenny Octavinawaty:** Conceptualization, Methodology, Supervision, Writing–review and editing. **Diah Andini:** Conceptualization, Methodology, Supervision, Project administration, Writing–review and editing. **Budiman Juniwijaya:** Investigation, Validation, Writing–review and editing. **Natasya Wanda Yuniza:** Investigation, Data curation, Writing–review and editing. **Nurdiansyah:** Investigation, Data curation, Writing–review and editing. **Dewie Susan:** Validation, Supervision, Writing–review and editing. **Ardy Oktaviandi:** Conceptualization, Methodology, Supervision, Validation, Writing–review and editing.

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