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Web-Based Digital Radiology Cuts Emergency Head CT Time in Limited-Resource Hospital

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Abstract

Rapid neuroimaging is critical in acute neurological emergencies, but film-based workflows in resource-limited hospitals often cause delays. This study evaluated a web-based digital radiology system embedded in EMR on emergency head CT turnaround times (TAT). A quasi-experimental pre-post study with independent samples was conducted at a private class C non-teaching hospital in East Java, Indonesia, comparing two six-month periods: pre-implementation (January–June 2023) and post-implementation (January–June 2025), separated by a 12-month stabilization period. Technical TAT (scan completion to digital upload) was assessed in 200 cases (100 pre, 100 post); clinical TAT (scan completion to final report) in 990 cases (485 pre, 505 post) using a census approach. Normality was tested using Shapiro-Wilk, followed by Mann-Whitney U test and chi-square test for quality standard achievement (≤15 minutes for technical TAT, ≤90 minutes for clinical TAT), with effect sizes (r, Phi) reported. Median technical TAT decreased from 19:04 to 11:12 minutes (41.3% reduction, U=2.000, $p<.001$, r=0.864), with ≤15-minute achievement rising from 0% to 98% (χ^2=192.157, $p<.001$, Phi=0.980). Median clinical TAT decreased from 1:49:00 to 1:09:00 hours (39.6% reduction, U=79,576.000, $p<.001$, r=0.303), with ≤90-minute achievement improving from 45.8% to 76.0% (χ^2=95.452, $p<.001$, Phi=0.311). This study shows that web-based digital radiology enhances emergency neuroimaging efficiency in limited-resource hospitals.

Introduction

Rapid neuroimaging is essential in acute neurological emergencies, where timely diagnosis directly influences patient outcomes (Saver *et al.*, 2013). In acute ischemic stroke, the principle of "time is brain" underscores this urgency, as every minute of delay corresponds to irreversible neural loss (Saver, 2006). The 2019 American Heart Association guidelines recommend non-contrast head CT as quickly as possible, with a target door-to-imaging time of ≤20 minutes (Powers *et al.*, 2019). Non-contrast head CT (NCCT) remains the first-line neuroimaging modality in acute neurological emergencies due to its high sensitivity for intracranial hemorrhage, widespread availability, and rapid acquisition time (Dieckmeyer *et al.*, 2023). Its primary advantage is the ability to rapidly exclude hemorrhagic stroke before initiating thrombolytic therapy, with AI-based software now achieving up to 96% sensitivity for hemorrhage detection (Gauriau *et al.*, 2023;Yedavalli *et al.*, 2023). However, NCCT has well-known limitations, including low sensitivity (approximately 40-60%) for acute ischemic changes within the first three hours, although recent deep learning models have substantially improved early infarct detection (Gauriau *et al.*, 2023). Current clinical practice trends show increasing utilization of non-contrast head CT, driven by its cost-effectiveness, shorter scan times compared

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to MRI, and the expanding role of tele-stroke networks that rely on CT-based decision-making (Powers *et al.*, 2019). Understanding these advantages and limitations is crucial for resource-limited hospitals, where balancing diagnostic accuracy, turnaround time, and cost constraints is particularly challenging.

Stroke remains a leading cause of death and disability globally (Johnson & Feigin, 2019). Despite this imperative, many resource-limited hospitals still rely on manual film-based workflows involving printing, physical transport, and manual retrieval, which prolong turnaround times (TAT) and increase variability (Šedová *et al.*, 2025). Digital transformation in radiology has been proposed as a solution. Integration of Picture Archiving and Communication Systems (PACS) with Electronic Medical Records (EMR) has been shown to reduce radiology TAT significantly (Krishnaraj *et al.*, 2010; Ratib *et al.*, 2003). However, full-scale PACS requires substantial investment, making it less accessible for limited-resource hospitals (Marey *et al.*, 2025). Studies on decentralized health systems in low- and middle-income countries have found that uneven institutional capacity and limited fiscal resources often constrain service quality improvements (Witcahyo *et al.*, 2025). Similarly, integrated referral systems and multi-sector collaboration are critical for effective health crisis management in resource-limited settings (Handayani *et al.*, 2024). Furthermore, the integration of clinical data across healthcare facilities through web-based EMR systems has been identified as a critical enabler for improving service quality and care continuity in Indonesia (Kurniadi & Pratiwi, 2017). Their proposed open-source model for clinical data exchange supports the feasibility of implementing cost-effective digital solutions in limited-resource settings.

Four research gaps remain: (1) evidence primarily from high-resource settings, (2) failure to distinguish technical vs. clinical TAT, (3) limited data on web-based alternatives to full PACS, and (4) scarce evidence from Indonesian private hospitals. Previous research shows that EMR studies in developing countries remain limited and are still dominated by topics on hospitalization and medical record evaluation, while advanced digital health system applications remain underexplored (Utami & Arini, 2025). Furthermore, studies in developing country settings highlight the need for integrated health information systems to support clinical decision-making, reporting, and monitoring of disease screening programs (Arini *et al.*, 2024). Therefore, this study aimed to evaluate the impact of implementing a web-based EMR-embedded digital radiology distribution system on technical and clinical turnaround times, service consistency, and achievement of imaging quality standards in a resource-limited hospital setting.

Method

A quasi-experimental pre-post study with independent samples was conducted at the Radiology Department of a private class C non-teaching hospital in East Java, Indonesia. The study compared two six-month periods: pre-implementation (January–June 2023) and post-implementation (January–June 2025). A 12-month stabilization period between the two observation phases was applied to ensure system maturity and staff adaptation. The web-based digital radiology system was developed in-house by the hospital's IT team in collaboration with the radiology department. The development process followed four phases: (1) needs assessment through workflow observation and staff interviews (August–September 2023), (2) system design and prototyping (October 2023), (3) usability testing with 10 radiology staff (November 2023), and (4) refinement based on user feedback (December 2023). The system was implemented in January 2024. Key features included: transfer of images from CT scanner to central server, role-based authentication, web-based viewer accessible via any hospital computer, structured reporting module, and teleradiology capability. A structured transition period included two weeks of configuration, one week of staff training, and two weeks of parallel run.

A controlled trial with an external control group was not feasible for two reasons. First, the intervention was implemented hospital-wide as a quality improvement initiative, making it impossible to withhold the system from any patient group for ethical reasons.

Second, no comparable hospital in the region had similar infrastructure or patient volume to serve as a control site. Therefore, a pre-post design with independent samples was the most practical and ethically appropriate approach. The 12-month stabilization period and the absence of any major changes in CT equipment, staffing levels, or imaging protocols between the two periods strengthen the internal validity. The target population comprised patients with acute neurological indications requiring non-contrast head CT. The technical TAT sample (image availability) included 200 cases (100 pre, 100 post). The clinical TAT sample (final report availability) included 990 cases (485 pre, 505 post) using a census approach. Inclusion criteria were: acute neurological emergency warranting head CT and complete timestamp documentation. Exclusion criteria were: incomplete timestamp data and non-emergency or non-neurological indications.

Data were collected retrospectively by two trained research assistants following a standardized protocol. In the pre-implementation period, times were recorded manually using calibrated digital stopwatches. In the post-implementation period, times were recorded by observing digital upload timestamps in the EMR system. Quality control measures included 25% of cases measured independently by both assistants, logical sequence verification for all cases, and a 10% random sample cross-checked against ancillary timestamps. Statistical analyses were conducted using IBM SPSS Statistics version 25.0 (α=0.05, two-tailed). Normality was assessed using the Shapiro-Wilk test (Ghasemi & Zahediasl, 2012). The Mann-Whitney U test was employed as the primary inferential analysis (Nachar, 2008). Effect sizes were calculated using $r = |Z|/\sqrt{N}$, interpreted as small (0.10), medium (0.30), or large (0.50) (Fritz *et al.*, 2012). Achievement of quality standards ($\leq$15 minutes for technical TAT, $\leq$90 minutes for clinical TAT) was evaluated using Pearson's chi-square test with Phi coefficient. This research was approved by the Research Ethics Committee of the hospital (Approval No. 08/RSISA-KEPK/VIII/2025) on 5 August 2025. The study was conducted in accordance with the Declaration of Helsinki. All data were collected retrospectively and anonymized. The requirement for individual informed consent was waived by the ethics committee.

Result and Discussion

Two independent samples were analyzed. The technical TAT sample (n=200) assessed image availability time, while the clinical TAT sample (n=990) assessed final report availability time. Table 1 presents the demographic characteristics. Patient origin distribution reflected typical emergency service patterns, with emergency department cases comprising 20.8-36.0% of samples and inpatient wards representing the largest proportion (48.0-

TABLE 1. Demographic and Clinical Characteristics of Study Samples

Characteristic	Technical TAT (n=200)		Clinical TAT (n=990)	
	Pre [n (%)]	Post [n (%)]	Pre [n (%)]	Post [n (%)]
Gender				
Male	55[55]	48[48]	247[50.9]	255[50.5]
Female	45[45]	52[52]	238[49.1]	250[49.5]
Patient Origin				
Emergency Department	36[36]	40[40]	101[20.8]	131[25.9]
Inpatient Ward	48[48]	50[50]	321[66.2]	296[58.6]
Outpatient Clinic	16[16]	10[10]	63[13]	78[15.4]

Note: TAT=turnaround times

Source: Primary data processed (2025)

TABLE 2. Descriptive Statistics and Inferential Comparison of Turnaround Times

Parameter	Technical TAT		Clinical TAT	
	Pre (n=100)	**Post (n=100)**	**Pre (n=485)**	**Post (n=505)**
A. Descriptive Statistics				
Mean ± SD	18:57 ± 1:13	11:22 ± 0:59	4:26:36 ± 5:18:08	2:07:53 ± 2:49:01
Median (IQR)	19:04 (1:43)	11:12 (1:07)	1:49:00 (3:04:00)	1:09:00 (0:33:00)
Range	15:23-21:25	9:45-15:32	0:17:00-23:18:00	0:12:00-19:27:00
B. Normality Test (Shapiro-Wilk)				
Statistic	0.964	0.873	0.689	0.534
p-value	.008	<.001	<.001	<.001
C. Percentile Distribution				
5th percentile	16:41	10:05	46:18	32:00
25th percentile	18:07	10:48	1:06:00	56:00
50th percentile	19:04	11:12	1:49:00	1:09:00
75th percentile	19:50	11:55	4:10:00	1:29:00
95th percentile	20:39	13:05	16:12:41	9:13:24
D. Quality Standard Achievement				
Achievement (%)	0%	98%	45.8%	76.0%
Chi-square (χ^2)	192.157		95.452	
p-value	<.001		<.001	
E. Inferential Statistics				
Mann-Whitney U	U=2.000, <.001		U=79,576.000, <.001	
Effect Size (r)	r=0.864 (very large)		r=0.303 (medium-large)	

Note: TAT = turnaround time. Shapiro-Wilk test indicated significant departures from normality for all groups. Effect size r is interpreted according to Cohen's conventions (1988): small=0.10, medium=0.30, large=0.50; values >0.50 are considered very large.

Source: SPSS analysis output (2025)

66.2%).

The Shapiro-Wilk test indicated significant departures from normality for all groups (p<.001 for most groups, Technical TAT Pre p=.008), justifying non-parametric methods (Table 2). Following system implementation, technical TAT showed substantial improvement (Table 2). Median time decreased by 41.3% (from 19:04 to 11:12 minutes), and the interquartile range narrowed by 34.9% (from 1:43 to 1:07 minutes), indicating improved consistency. The Mann-Whitney U test confirmed a highly significant reduction (U=2.000, <.001) with a very large effect size (r=0.864). Achievement of the ≤15-minute quality standard increased dramatically from 0% to 98% (χ^2=192.157, <.001). Clinical TAT also improved significantly (Table 2). Median time decreased by 39.6% (from 1:49:00 to 1:09:00 hours), while the interquartile range showed a marked 82.1% reduction (from 3:04:00 to 0:33:00 hours), demonstrating substantially improved consistency. The Mann-Whitney U test indicated a highly significant improvement (U=79,576.000, <.001) with a medium-large effect size (r=0.303). The proportion of cases meeting the ≤90-minute standard increased from 45.8% to 76.0% (χ^2=95.452, <.001).

Table 3 summarizes the achievement of quality standards before and after implementation. For technical TAT, the ≤15-minute standard was achieved in 0% of cases pre-implementation compared to 98% post-implementation, with a very large effect size (Phi=0.980). For clinical TAT, achievement of the ≤90-minute standard increased from 45.8% to 76.0%, with a medium effect size (Phi=0.311). Both improvements were

TABLE 3. Quality Standard Achievement Before and After Implementation

Outcome	Pre	Post	χ^2	p-value	Phi
Technical TAT (≤15 min)	0%	98%	192.157	<.001	0.980 (Very large)
Clinical TAT (≤90 min)	45.8%	76.0%	95.452	<.001	0.311 (Medium)

Note: χ^2 = Chi-square statistic. Phi effect size interpreted according to Cohen's conventions (1988): small=0.10, medium=0.30, large=0.50
Source: SPSS analysis output (2025)

TABLE 4. Subgroup Analysis of Clinical TAT Standard Achievement (≤90 min)

Subgroup	Pre (%)	Post (%)	Absolute Change (pp)
Emergency Department	51.9	81.3	+29.4
Inpatient Ward	39.5	68.8	+29.3
Outpatient Clinic	40.6	84.0	+43.4

Note: pp = percentage points
Source: SPSS analysis output (2025)

TABLE 5. Robust M-Estimators of Turnaround Times (TAT)

TAT Type	Range of M-Estimators	% Reduction
Technical TAT	19:03 - 19:06 → 11:12 - 11:16	40.9 - 41.3
Clinical TAT	1:32:48 - 1:58:10 → 1:04:53 - 1:11:06	39.8 - 45.2

Note: M-estimators (Huber's, Tukey's biweight, Hampel's, Andrews' wave) provide robust central tendency estimates resistant to outliers.
Source: SPSS analysis output (2025)

statistically significant (<.001).

Subgroup analysis revealed improved clinical TAT standard achievement across all categories (Table 4). The greatest absolute improvement occurred in outpatient clinic cases (43.4 percentage points, from 40.6% to 84.0%), followed by emergency department cases (29.4 percentage points, from 51.9% to 81.3%) and inpatient ward cases (29.3 percentage points, from 39.5% to 68.8%).

Robust statistical confirmation using M-estimators showed consistent reductions across different estimation methods (Table 5). Technical TAT decreased by 40.9-41.3% across Huber's, Tukey's biweight, Hampel's, and Andrews' wave estimators. Clinical TAT decreased by 39.8-45.2% across the same methods, confirming that the observed improvements were not driven solely by extreme values.

This study demonstrates that implementing a web-based EMR-embedded digital radiology distribution system significantly improved both technical and clinical turnaround times for emergency head CT scans in a resource-limited Indonesian hospital. Substantial reductions were observed with very large and medium-large effect sizes, indicating meaningful operational impact (Fritz *et al*., 2012). The near-perfect achievement of technical TAT standards demonstrates that eliminating physical film processing addresses a fundamental bottleneck in emergency neuroimaging (Šedová *et al*., 2025). This finding aligns with systematic reviews indicating that integrated digital systems can reduce radiology TAT by 54% in well-resourced settings (Krishnaraj *et al*., 2010). Our study extends this evidence to resource-limited private hospitals, showing even more substantial improvements than those reported in tertiary centers (Marey *et al*., 2025). In contrast, clinical TAT showed substantial but incomplete optimization. This differential outcome reflects the distinction between automated technical processes and human-dependent clinical workflows. Digital systems can automate image distribution reliably, but radiologist interpretation faces constraints, including case complexity and workload (Reiner *et al*., 2007). This pattern aligns with previous studies showing that automated interventions significantly reduce image acquisition time while having more modest effects on interpretation intervals (Wood *et al.*, 2023). Recent evidence from Ethiopia further supports the effectiveness of web-based digital solutions in resource-limited settings (Nigatu *et al.*, 2025).

The substantial improvement in emergency department case compliance indicates particular value for time-sensitive cases, supporting targeted optimization of acute stroke pathways (Wei *et al.*, 2025). Beyond mean time reductions, the dramatic enhancement of service consistency, particularly the reduction in clinical TAT variability, represents an equally important outcome. High variability creates operational uncertainty that complicates clinical decision-making and resource planning (Hains *et al.*, 2012). The reduction indicates that digital systems mitigate extreme delays, with previously delayed cases benefiting disproportionately (Šedová *et al.*, 2025). Sustained improvement across all post-implementation months indicates that the digital system has been effectively integrated into routine workflows rather than representing a temporary change (Šedová *et al.*, 2025). The observation that the lowest-performing post-implementation month exceeded the best pre-implementation month reflects a fundamental elevation of baseline performance.

All patient subgroups demonstrated improved clinical TAT standard achievement following system implementation, with outpatient clinic cases showing the greatest improvement. Importantly, emergency cases still showed substantial gains, supporting the intervention's value for time-sensitive neurological emergencies (Wei *et al.*, 2025). The absence of new disparities across subgroups suggests digital transformation can improve efficiency without exacerbating existing access differences (Marey *et al.*, 2025). The success of health system interventions depends on strong multi-stakeholder coordination. Hermawan *et al.* (2025) demonstrated that Pentahelix collaboration involving government, private sector, academics, community, and media is crucial for effective health service delivery, reinforcing our finding that digital system implementation requires coordination across IT, radiology, and clinical departments. The reduction in technical TAT of approximately 8 minutes carries clinical significance. Based on Saver's quantification of 1.9 million neurons preserved per minute of earlier reperfusion, this improvement translates to approximately 15 million neurons potentially preserved per patient (Saver, 2006;Wood *et al.*, 2023). The web-based architecture offers particular advantages for resource-limited settings, including lower implementation costs, easier maintenance, and built-in teleradiology capability (Nigatu *et al.*, 2025;Kamel & Nagy, 2018).

Digital health interventions, including telemonitoring systems, have been shown to improve patient outcomes and reduce hospital readmissions (Hariyono *et al.*, 2025). Their findings support our result that web-based digital radiology systems can significantly reduce turnaround times through automated image distribution. For hospital administrators, these findings support investment in cost-conscious digital workflow redesign. For clinicians, the increased predictability of image and report availability enhances confidence in acute care decision-making (Wei *et al.*, 2025). Unlike enterprise-level commercial PACS, the web-based EMR-embedded system represents a more accessible alternative for resource-limited hospitals (Marey *et al.*, 2025;Nigatu *et al.*, 2025). The successful implementation of digital health systems requires attention to both technological and human factors. Research has shown that the development of medical record technology and information systems significantly improves employee performance in hospital settings (Sutanto & Arini, 2025). Furthermore, healthcare workers' acceptance of electronic medical records is significantly influenced by their e-health literacy, which plays a crucial role during the system transition (Noeryosan *et al.*, 2024). The integration of digital innovations, such as natural language processing, can further enhance patient-centered care by improving data processing and clinical decision support (Putra *et al.*, 2024). The implementation of integrated health information systems using digital technology faces barriers, including individual behavior, data governance, and communication networks

(Eryando & Afrizal, 2024). This finding aligns with our observation that staff training and system usability testing were crucial for successful digital radiology implementation in this limited-resource hospital.

This study has several notable strengths. First, the quasi-experimental design allowed the evaluation of a system-wide intervention (Arini *et al.*, 2024). Second, the distinction between technical and clinical TAT provides nuanced insights. Third, comprehensive statistical analysis strengthens confidence in the findings (Fritz *et al.*, 2012). Fourth, the focus on a resource-limited private hospital addresses an underrepresented setting (Marey *et al.*, 2025). Several limitations warrant consideration. First, the single-center design may limit generalizability. Second, the lack of randomization means unmeasured confounding factors could influence results. Third, manual time measurement introduces potential measurement error. Fourth, the study did not assess clinical outcomes or cost-effectiveness. Fifth, the stabilization period means the study cannot capture very long-term sustainability. Multi-center studies are needed to enhance generalizability (Smith *et al.*, 2020). Investigations linking process improvements to clinical outcomes would strengthen the evidence base (Wei *et al.*, 2025). Economic evaluations would help determine cost-benefit ratios. Longitudinal studies should examine long-term sustainability. Qualitative investigations could identify facilitators and barriers to optimal utilization (Listiowati *et al.*, 2025).

Conclusion

Implementation of a web-based EMR-embedded digital radiology system significantly reduced technical and clinical turnaround times for emergency head CT scans in a limited-resource hospital. The reductions were statistically significant with very large to medium-large effect sizes, and improvements in quality standard achievement were substantial. These benefits were sustained across the post-implementation period and consistent across all patient subgroups. This finding aligns with previous research demonstrating that the development of medical record technology and information systems improves employee performance in hospital settings. Moreover, successful adoption of electronic medical records is influenced by healthcare workers' e-health literacy and acceptance of the system transition. The integration of digital innovations, including natural language processing, further enhances patient-centered care through improved data processing.

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