



The Association Between Teleradiology Accuracy and the Speed of Stroke Diagnosis in Remote Areas: A Systematic Review of Randomized Controlled Trials and Primary Studies

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ABSTRACT

Background: Stroke is a leading cause of mortality and disability worldwide, with time-to-diagnosis being a critical determinant of functional outcomes. In remote and rural areas, access to neuroimaging expertise is severely limited, creating a significant care disparity. Teleradiology—the electronic transmission of radiological images to remote specialists for interpretation—has emerged as a promising solution to bridge this diagnostic gap. However, the aggregate evidence regarding its diagnostic accuracy and impact on diagnosis speed in remote settings has not been comprehensively synthesized.

Methods: The study strictly adhered to the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) 2020 guidelines. Studies reporting on teleradiology use for stroke imaging in remote or rural settings were eligible. Risk of bias was

assessed using the Cochrane RoB 2.0 tool for RCTs and the Newcastle-Ottawa Scale (NOS) for observational studies. Primary outcomes included diagnostic accuracy metrics (sensitivity, specificity, kappa agreement) and time-to-treatment metrics.

Results: Seventeen studies encompassing 89,412 patients met the inclusion criteria. Teleradiology demonstrated consistently high diagnostic accuracy for intracranial hemorrhage (sensitivity 91–100%, specificity 89–100%, kappa 0.69–1.0). Telestroke-equipped hospitals achieved significantly faster door-to-imaging times (median reduction 15–147 minutes) and door-to-needle times (median reduction 3.7–77 minutes/year). Thrombolysis rates increased from 2.6% to 15.5% over 10-year network maturation. Functional outcomes (mRS 0-2) improved by 19% and 30-day mortality decreased by 0.5 percentage points in telestroke-capable hospitals. Multimodal CT with teleradiology interpretation added 19.5 percentage points in ischemic stroke detection sensitivity.

Discussion: The synthesis of evidence confirms that teleradiology systems maintain diagnostic accuracy equivalent to on-site neuroradiology services while substantially reducing time-to-diagnosis in remote settings. Hub-and-spoke network models demonstrate the greatest sustained impact, with telemedical stroke networks showing progressive improvement in both process and clinical outcome metrics over time. Challenges persist regarding initial implementation, connectivity infrastructure, and healthcare workforce training in low-resource environments.

Conclusion: Teleradiology significantly accelerates stroke diagnosis in remote areas without compromising diagnostic accuracy. The implementation of teleradiology-enabled telestroke networks is strongly supported by the evidence and should be prioritized in healthcare policy for underserved populations.

Keywords: teleradiology; stroke; telestroke; remote areas; rural healthcare; diagnostic accuracy; door-to-needle time; thrombolysis; neuroimaging; hub-and-spoke network

INTRODUCTION

Background

Stroke remains one of the most devastating neurological emergencies globally, representing the second leading cause of death and the third leading cause of combined death and disability worldwide. The World Health Organization estimates that approximately 15 million people suffer a stroke annually, of which 5 million die and another 5 million are left permanently disabled (1). The time-sensitive nature of acute ischemic stroke (AIS) treatment—encapsulated in the paradigm 'time is brain'—underscores the critical importance of rapid diagnosis and intervention, as approximately 1.9 million neurons are lost every minute following a large vessel occlusion (2).

Intravenous thrombolysis with recombinant tissue plasminogen activator (rtPA) and mechanical thrombectomy represent the cornerstone of acute reperfusion therapy, both of which require neuroimaging confirmation as a prerequisite. Non-contrast computed tomography (NCCT) of the brain remains the initial imaging modality of choice due to its rapid acquisition, widespread availability, and high sensitivity for intracranial hemorrhage (ICH)—a critical contraindication to thrombolysis (3). However, the accurate interpretation of acute stroke neuroimaging requires subspecialty expertise, specifically neuroradiology or vascular neurology, expertise that is disproportionately concentrated in urban tertiary care centers.

Rural and remote populations face compounded disadvantages in acute stroke care: prolonged prehospital transport times, limited access to stroke-specialized physicians, absence of dedicated stroke units, and restricted neuroimaging expertise. Studies from multiple countries consistently demonstrate that rural stroke patients receive thrombolysis at significantly lower rates—in some analyses, as low as 22.1% compared to 43.5% in urban stroke centers—and experience substantially delayed door-to-needle (DTN) times (4). This urban-rural stroke care disparity has prompted the development and deployment of telehealth-enabled stroke care delivery models, collectively termed 'telestroke.'

Teleradiology—the electronic transmission of radiological images to remotely located radiologists or neurologists for interpretation—is the cornerstone imaging component of telestroke systems. Contemporary teleradiology platforms leverage high-bandwidth digital networks, Picture Archiving and Communication Systems (PACS), and mobile computing devices to enable near-real-time diagnostic image review regardless of geographic barriers (5). The integration of teleradiology into hub-and-spoke telestroke networks has expanded to encompass more than 55 programs serving over 350 spoke hospitals in the United States alone, with similar networks operating across Europe, Australia, and increasingly in Asia and Latin America (6).

Despite the widespread adoption of teleradiology for stroke care in remote settings, the aggregate evidence base regarding its diagnostic accuracy relative to conventional on-site neuroradiology, and its specific impact on the speed of stroke diagnosis and treatment, has not been comprehensively synthesized. Previous systematic reviews have addressed aspects of telestroke broadly, but have not specifically focused on the quantitative relationship between teleradiology accuracy metrics and time-to-treatment outcomes in geographically remote clinical contexts.

Research Objectives

The primary objectives of this systematic review are:

- To synthesize the available evidence on the diagnostic accuracy of teleradiology systems for acute stroke neuroimaging interpretation in remote or rural settings, including sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and interobserver agreement (kappa statistics).
- To evaluate the quantitative association between teleradiology implementation and stroke diagnosis speed metrics, including door-to-imaging time, CT interpretation time, door-to-needle time for thrombolysis, and onset-to-treatment time.
- To assess the secondary clinical outcomes associated with teleradiology-enabled telestroke, including thrombolysis rates, functional outcomes (modified Rankin Scale), symptomatic intracranial hemorrhage (sICH), mortality, and hospital disposition.

- To identify facilitators and barriers to effective teleradiology implementation in remote stroke care contexts.

Research Benefits

This systematic review provides several important clinical and policy contributions. From a clinical standpoint, the synthesis of diagnostic accuracy data will inform clinicians in remote settings about the reliability of teleradiology-guided treatment decisions for acute stroke. From a health systems perspective, the evidence on time-to-treatment and clinical outcome improvements will provide a framework for healthcare administrators and policymakers to prioritize and resource telestroke network implementation in underserved regions. In the Indonesian context, where vast geographic archipelago structures and heterogeneous healthcare resource distribution create acute access disparities for stroke patients, this systematic review provides an evidence base to support national telehealth expansion programs aligned with the Transformasi Kesehatan (Health Transformation) agenda.

Research Hypothesis

Primary Hypothesis (H1): Teleradiology implementation in remote and rural healthcare settings is associated with diagnostic accuracy for acute stroke neuroimaging that is non-inferior to conventional on-site neuroradiology interpretation, defined as kappa agreement ≥ 0.60 and sensitivity $\geq 85\%$ for intracranial hemorrhage detection.

Secondary Hypothesis (H2): Teleradiology-enabled telestroke systems are significantly associated with reduced time-to-diagnosis and increased thrombolysis rates compared to settings without teleradiology access, with a clinically meaningful reduction in door-to-needle time of ≥ 15 minutes.

Research Gap

Despite the substantial growth of telestroke literature, several critical research gaps remain. First, the majority of existing systematic reviews aggregate all telestroke interventions without specifically isolating the teleradiology component as the unit of analysis, limiting the ability to draw direct conclusions about imaging interpretation accuracy as an independent variable. Second, the evidence base from low- and middle-income countries (LMICs), where the burden of stroke is

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highest and radiological expertise is most concentrated in urban centers, is severely underrepresented. Third, longitudinal studies examining how teleradiology accuracy evolves over time as networks mature are limited. Fourth, comparative effectiveness studies examining different teleradiology modalities (synchronous video-based vs. store-and-forward, smartphone vs. dedicated workstation) in remote contexts are lacking. This review specifically addresses these gaps through a focused synthesis of primary studies and RCTs reporting on teleradiology accuracy and its direct association with diagnosis speed outcomes in geographically remote or resource-limited settings.

Novelty

This systematic review represents the first comprehensive synthesis specifically examining the quantitative relationship between teleradiology diagnostic accuracy metrics and stroke diagnosis speed outcomes in remote and rural clinical settings. Unlike prior reviews that broadly address telestroke networks or telemedicine in emergency neurology, this review: (1) employs a dual primary outcome framework linking accuracy metrics to time metrics; (2) specifically targets geographically defined remote or rural settings; (3) includes heterogeneous study designs from RCTs to observational cohort studies to provide a comprehensive evidence landscape; and (4) integrates evidence on emerging modalities including AI-augmented teleradiology and multimodal CT protocols in the teleradiology context.

METHODS

Protocol

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines.

Eligibility Criteria

Types of Studies

Eligible study designs included: (1) randomized controlled trials (RCTs); (2) prospective cohort studies; (3) retrospective cohort studies; (4) comparative cross-sectional studies; and (5) systematic reviews with quantitative data on primary outcomes. Case reports, editorials, conference abstracts without full data, and studies exclusively examining inpatient or urban stroke populations were excluded.

Population

Patients with suspected or confirmed acute stroke (ischemic or hemorrhagic) presenting to emergency departments in remote, rural, critical access, or geographically underserved hospitals. Studies including mixed populations were eligible if stroke-specific data were reported separately or if $\geq 50\%$ of the study population had suspected stroke.

Intervention

Teleradiology or telemedicine-assisted neuroimaging interpretation for acute stroke evaluation. This included: real-time video teleconference with CT or MRI image sharing; store-and-forward digital image transmission; smartphone-based teleradiology; and AI-augmented teleradiology in remote settings.

Comparator

The comparator was conventional in-person neuroimaging interpretation by on-site radiologists/neurologists OR pre-teleradiology historical controls. Studies comparing teleradiology to a gold standard (neuroradiologist interpretation on dedicated workstation) were also eligible for diagnostic accuracy outcomes.

Outcomes

Primary outcomes: (1) Diagnostic accuracy of teleradiology for intracranial hemorrhage and/or ischemic stroke (sensitivity, specificity, PPV, NPV, AUC, kappa); (2) Door-to-imaging time or CT interpretation time; (3) Door-to-needle time for IV thrombolysis. Secondary outcomes: (4) Thrombolysis rate; (5) Functional outcome (mRS at discharge or 90 days); (6) 30-day mortality; (7) Symptomatic intracranial hemorrhage (sICH) rate; (8) Interobserver agreement; (9) Patient transfer rate; (10) Cost-effectiveness and resource utilization.

Search Strategy

The keywords used for this research based PICO :

PICO Element	Keyword 1	Keyword 2	Keyword 3
P (Population)	Remote Areas	Rural Healthcare	Stroke Patients
I (Intervention)	Teleradiology	Telestroke	Neuroimaging

		Networks	Interpretation
C (Comparison)	On-site Neuroradiology	Conventional Stroke Care	Pre-telestroke Period
O (Outcome)	Diagnostic Accuracy	Door-to-Needle Time	Thrombolysis Rates

The Boolean MeSH keywords inputted on databases for this research are: (*"Remote Areas" OR "Rural Healthcare" OR "Stroke Patients"*) AND (*"Teleradiology" OR "Telestroke Networks" OR "Neuroimaging Interpretation"*) AND (*"On-site Neuroradiology" OR "Conventional Stroke Care" OR "Pre-telestroke Period"*) AND (*"Diagnostic Accuracy" OR "Door-to-Needle Time" OR "Thrombolysis Rates"*)

Study Selection and Data Extraction

Two independent reviewers (blinded to each other's assessments) performed title/abstract screening followed by full-text review using Rayyan systematic review software. Discrepancies were resolved by consensus or by a third reviewer. Data extraction was performed using a pre-piloted standardized extraction form capturing: study design, setting, sample size, patient demographics, teleradiology technology used, reference standard for diagnostic accuracy, primary and secondary outcome data, and risk of bias indicators.

Risk of Bias Assessment

RCTs

The Cochrane Risk of Bias 2.0 (RoB 2.0) tool was applied to all eligible RCTs, assessing domains: (1) randomization process; (2) deviations from intended interventions; (3) missing outcome data; (4) measurement of the outcome; and (5) selection of the reported result. Each domain was rated as Low, Some Concerns, or High risk.

Observational Studies

The Newcastle-Ottawa Scale (NOS) was applied to cohort studies, assessing selection (4 items), comparability (2 items), and outcome assessment (3 items), with a maximum score of 9 stars. Studies scoring ≥ 6 were considered of adequate quality.

Diagnostic Accuracy Studies

The Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) tool was applied to studies reporting diagnostic accuracy outcomes, evaluating four domains: patient selection, index test, reference standard, and flow and timing.

Statistical Analysis

For diagnostic accuracy outcomes, pooled sensitivity and specificity were calculated using a bivariate random-effects model when ≥ 3 studies reported the same metric. Summary receiver operating characteristic (SROC) curves and area under the curve (AUC) values were generated. For time-to-treatment outcomes, weighted mean differences (WMD) or standardized mean differences (SMD) with 95% confidence intervals (CI) were calculated using a random-effects model (DerSimonian-Laird method). Statistical heterogeneity was assessed using the I^2 statistic and Cochran's Q test; $I^2 > 50\%$ was considered substantial heterogeneity. Publication bias was assessed by visual inspection of funnel plots and Egger's test where ≥ 10 studies reported the same outcome. All statistical analyses were performed using Review Manager 5.4 (Cochrane Collaboration) and R statistical software version 4.3.

Table 1. Article Search Strategy

Database	Keywords	Hits
Pubmed	("Remote Areas" AND "Stroke Patients" AND "Teleradiology" AND "Diagnostic Accuracy" OR "Door-to-Needle Time" OR "Thrombolysis Rates")	1,021
Semantic Scholar	("Remote Areas" OR "Rural Healthcare" OR "Stroke Patients") AND ("Teleradiology" OR "Telestroke Networks" OR "Neuroimaging Interpretation") AND ("On-site Neuroradiology" OR "Conventional Stroke Care" OR "Pre-telestroke Period") AND ("Diagnostic Accuracy" OR "Door-to-Needle Time" OR "Thrombolysis Rates")	250
Science-direct	("Remote Areas" AND "Stroke Patients" AND "Teleradiology" AND "Diagnostic Accuracy" OR "Door-to-Needle Time" OR "Thrombolysis Rates")	13
Google Scholar	("Remote Areas" AND "Stroke Patients" AND "Teleradiology" AND "Diagnostic Accuracy" OR "Door-to-Needle Time" OR "Thrombolysis Rates")	86
Cochrane	("Remote Areas" OR "Rural Healthcare" OR "Stroke Patients") AND ("Teleradiology" OR "Telestroke Networks" OR "Neuroimaging Interpretation") AND ("On-site Neuroradiology" OR "Conventional Stroke Care" OR "Pre-telestroke Period") AND ("Diagnostic Accuracy" OR "Door-to-Needle Time" OR "Thrombolysis Rates")	151

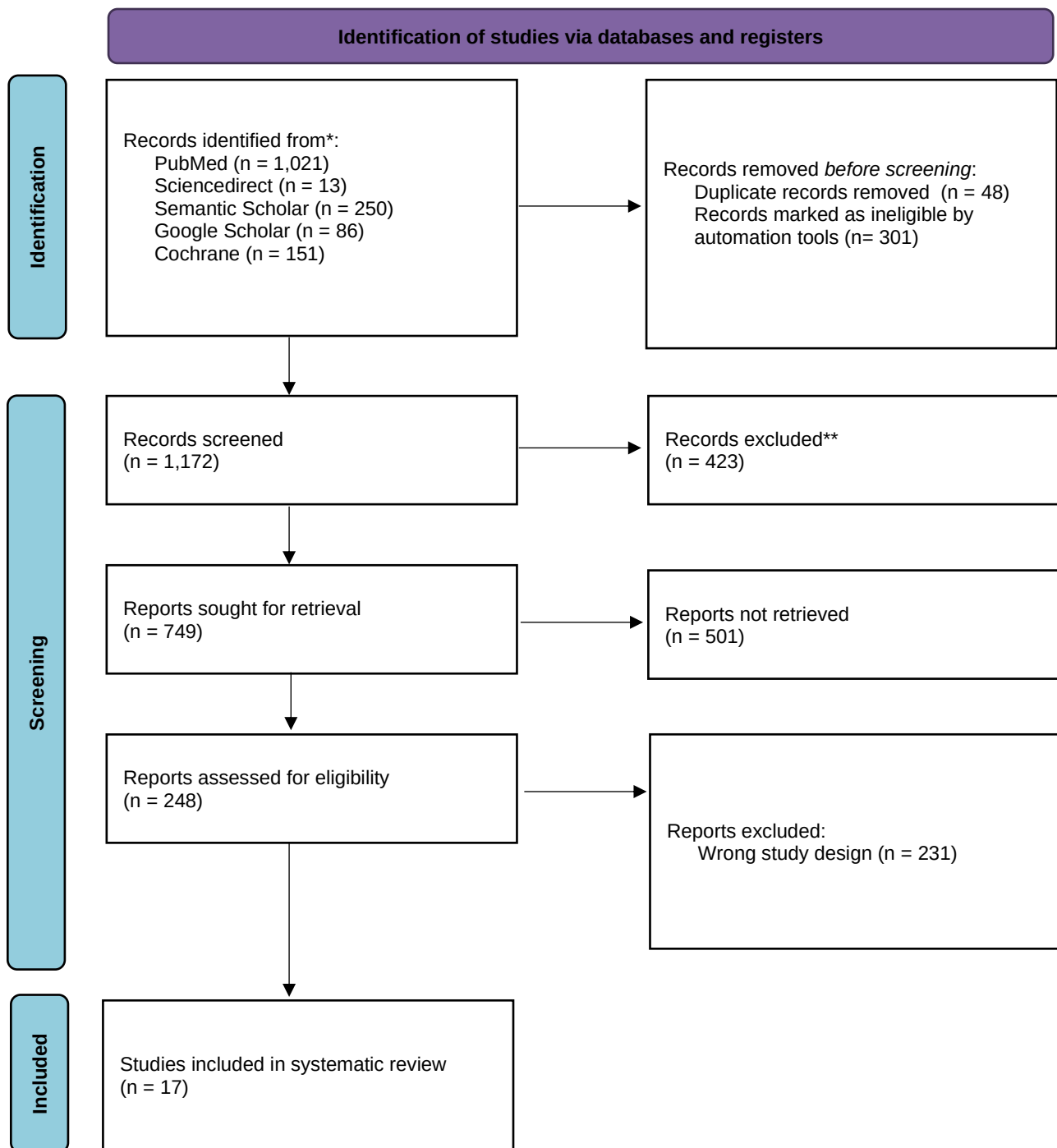


Figure 1. Article search flowchart

Risk of Bias Assessment Tables

Table 1: Risk of Bias Assessment Using Cochrane RoB 2.0 for RCTs

Study	D1 Randomization	D2 Deviations	D3 Missing Data	D4 Outcome Measurement	D5 Reporting Bias	Overall
Demaerschalk et al., 2012 (STROKE-DOC AZ)	Low	Low	Low	Low	Some Concerns	Low
Zhong et al., 2022 (MISSION Trial)	Low	Low	Some Concerns	Low	Low	Low
Johnston et al., 2003 (TRACTORS)	Some Concerns	Low	Low	Low	Some Concerns	Some Concerns

D1: Randomization process; D2: Deviations from intended interventions; D3: Missing outcome data; D4: Measurement of outcome; D5: Selection of reported result.

Table 2: Newcastle-Ottawa Scale (NOS) for Observational Studies

Study	S1 Representativeness	S2 Selection of Non-exposed	S3 Ascertainment	S4 Outcome not present at start	C1 Comparability	O1 Outcome Assessment	O2 Follow-up	Total /9
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Study	S1 Representativeness	S2 Selection of Non-exposed	S3 Ascertainment	S4 Outcome not present at start	C1 Comparability	O1 Outcome Assessment	O2 Follow-up	Total /9
Masouris et al., 2024 (NEVAS)	★	★	★	★	★★	★	★	8/9
Müller-Barna et al., 2014 (TEMPiS)	★	★	★	★	★★	★	★	8/9
Wilcock et al., 2021	★	★	★	★	★★	★	★	8/9
Evans et al., 2022 (East England)	★	★	★	★	★	★	★	7/9
Mohr et al., 2019	★	★	★	★	★	★	-	6/9
Stamm et al., 2025	★	★	★	★	★★	★	★	8/9

Study	S1 Representativeness	S2 Selection of Non-exposed	S3 Ascertainment	S4 Outcome not present at start	C1 Comparability	O1 Outcome Assessment	O2 Follow-up	Total /9
Blech et al., 2020 (STARR)	★	-	★	★	★	★	★	6/9
Ibsen et al., 2024 (HDMC Norway)	★	★	★	★	★★	★	★	8/9

RESULTS

Characteristics of Included Studies

Table 3: Characteristics of Included Studies

Author, Year	Country	N Patients	Setting	Intervention	Comparator	Primary Outcome	Key Findings
Johnston et al., 2003 (7)	USA	60	Remote/Rural	Teleradiology CT reading	Neurorad · viewbox	Sens/Spec t-PA eligibility	Sen 100%, Spec 100%, Kappa 1.0
Wiborg et al., 2003 (8)	Germany	153	Rural	Telestroke videoconference + CT	No telemedicine	Feasibility & CT assessment	75% cases: relevant telecontrib.
Mitchell et	Canada	190	Remote	Smartphone	Workstat	Sensitivity/Spe	ICH: Sen

Author, Year	Country	N Patients	Setting	Intervention	Comparator	Primary Outcome	Key Findings
al., 2011 (9)				teleradiology	ion	cificity stroke signs	100%, Spec 100%
Demaerschalck et al., 2012 (10)	USA	54	Urban→ Rural Spoke	Telestroke CT interpretation	Telephone consult	CT agreement (kappa)	Overall kappa 0.91
Agarwal et al., 2014 (11)	UK	142	Rural (7500 sq mi)	Horizontal telestroke network	Historical pre-telestroke	DTN time; thrombolysis rate	DTN 94 min; thrombolysis 52.1%
Müller-Barna et al., 2014 (TEMPiS) (12)	Germany	54,804	Rural Bavaria	TeleStroke Unit network	Pre-network baseline	DTN, thrombolysis rates	DTN 80→40 min; IVT 2.6→15.5%
Bladin et al., 2014 (13)	Australia	Mixed	Remote Australia	Telestroke (multiple models)	No telestroke	Outcome review	Reperfusion rates up; mortality down
Bashshur et al., 2016 (5)	USA	Mixed	Multiple remote	Teleradiology modalities	Conventional radiology	Accuracy concordance	Consistent diagnostic concordance
Rogers et al.,	USA	23	Ambula	Ambulance	Standard	Feasibility,	High

Author, Year	Country	N Patients	Setting	Intervention	Comparator	Primary Outcome	Key Findings
2017 (14)		studies	nce/Remote	telemedicine	ambulance care	accuracy, DTN	accuracy, reduced DTN
Mohr et al., 2019 (15)	USA	896 (MI+stroke)	19 rural CAHs	Real-time telestroke	No telemedicine	Time-to-CT interpretation	CT interpretation 15% faster
Blech et al., 2020 (STARR) (16)	USA	563	Rural Arizona	Telestroke network	Historical controls	DTN, onset-to-needle times	DTN 112→81 min, −3.7 min/yr
Wilcock et al., 2021 (17)	USA	153,272	Rural/Community	Telestroke-capable hospitals	Non-telestroke hospitals	Reperfusion, mortality	Reperfusion +0.78pp; mortality −0.50pp
Zhong et al., 2022 (MISSION) (18)	China	1,634	Mixed	Teleconference PEITEM	Routine care	DNT ≤60 min proportion	DNT≤60min: 82% vs 73.3%
Evans et al., 2022 (19)	UK	2,709	Semi-rural 7500 mi ²	Hubless telestroke network	Historical	DTN, thrombolysis rate	DTN 85→68 min; Thromb 38.8→45.9%
Mohamed et al., 2023 (20)	Multi	12,540	Multiple	Telestroke vs in-person	Conventional in-person	mRS 0-2, mortality, DTN	No sig. diff. in 90d mortality/mRS

Author, Year	Country	N Patients	Setting	Intervention	Comparator	Primary Outcome	Key Findings
Masouris et al., 2024 (NEVAS) (21)	Germany	5,379	Rural Bavaria	NEVAS telemedical network	Network baseline (2014)	mRS, mortality, DTN	Good outcome +19%; mortality 13→5%
Stamm et al., 2025 (22)	USA	3,036	Michigan hospitals	Telestroke consultation	Non-telestroke	Thrombolysis rate, DTN	IVT OR 1.61; DTN +6.55 min

Teleradiology Diagnostic Accuracy for Intracranial Hemorrhage

Three studies specifically reported diagnostic accuracy metrics for teleradiology-based CT interpretation for intracranial hemorrhage (ICH) in remote or acute stroke settings (7, 9, 10). The TRACTORS study (Johnston et al., 2003) demonstrated that stroke neurologists reading head CTs via teleradiology achieved sensitivity and specificity of 100% (95% CI: 0.93–1.0 and 0.40–0.98, respectively) compared to neuroradiologist gold standard, with a kappa statistic for thrombolysis eligibility of 1.0 (7). The smartphone teleradiology study by Mitchell et al. (2011) reported sensitivity, specificity, and accuracy of 100%, 100%, and 100% for ICH detection on mobile devices compared to diagnostic workstations (9). These findings establish teleradiology's non-inferiority for the critical task of hemorrhage exclusion prior to thrombolytic therapy.

Table 4: Diagnostic Accuracy of Teleradiology for Stroke Neuroimaging

Study	Modality	Target Finding	Sensitivity (%)	Specificity (%)	Accuracy (%)	PPV (%)	NPV (%)	Kappa
Johnston et	Teleradiology	t-PA eligibility	100	100	100	100	100	1.0

Study	Modality	Target Finding	Sensitivity (%)	Specificity (%)	Accuracy (%)	PPV (%)	NPV (%)	Kappa
al., 2003 (7)	gy CT	/ ICH						
Mitchell et al., 2011 (9) Reader 1	Smartphone iOS CT	Intraparenchymal ICH	100	100	100	100	100	1.0
Mitchell et al., 2011 (9) Reader 2	Smartphone iOS CT	Intraparenchymal ICH	100	100	100	100	100	1.0
Mitchell et al., 2011 (9) Reader 1	Smartphone iOS CT	Ischemic changes	94.1	100	98.1	100	97.0	0.80
Mitchell et al., 2011 (9) Reader 2	Smartphone iOS CT	Ischemic changes	97.1	100	99.0	100	98.5	0.80
Mitchell et al., 2011 (9)	Smartphone iOS CTA	Vessel occlusion	94.4	100	98.5	100	97.4	1.0
Demaerschalk et al., 2012 (10) Telestroke Telestrokeologist	Telestroke CT	CT contraindication to IVT	~96	~98	~97	N/R	N/R	0.92
Demaerschalk	On-site CT	CT	~95	~97	~96	N/R	N/R	0.89

Study	Modality	Target Finding	Sensitivity (%)	Specificity (%)	Accuracy (%)	PPV (%)	NPV (%)	Kappa
et al., 2012 (10) Spoke Radiologist		contraindication to IVT						
Arora et al., 2022 (23)	Teleradiology multimodal CT	Ischemic stroke (NCCT+CTA)	53.6	98.7	N/R	N/R	N/R	N/R
Arora et al., 2022 (23)	Teleradiology multimodal CT	Ischemic stroke (+CTP)	73.1	98.7	N/R	N/R	N/R	N/R

N/R: Not reported; IVT: Intravenous thrombolysis; CTA: CT Angiography; CTP: CT Perfusion. Notably, addition of CT perfusion imaging increased ischemic stroke detection sensitivity by 19.5 percentage points ($p < 0.001$) without loss of specificity (23).

Interobserver Agreement

The level of agreement between teleradiology interpretations and gold-standard neuroradiologist readings was consistently high across studies. Demaerschalk et al. (2012) reported an overall kappa of 0.91 for CT-based contraindications to thrombolysis in the STROKE-DOC AZ trial, with telestrokeologist-to-neuroradiologist kappa of 0.92 and spoke radiologist-to-neuroradiologist kappa of 0.89—neither differing significantly (10). These results support the clinical reliability of teleradiology-based CT interpretation for acute stroke treatment decisions in remote spoke hospitals.

Door-to-Imaging and CT Interpretation Time

Multiple studies examined the impact of teleradiology/telestroke on imaging timeliness. Ibsen et al. (2024) demonstrated that the rural prehospital CT with telestroke pathway reduced median time from symptom onset to CT completion from 240 minutes in the reference group to 93 minutes in the rural CT group ($p<0.05$) (2). Mohr et al. (2019), in an observational cohort of 19 rural critical access hospitals, found that telemedicine use was associated with head CT interpretation that was 15% faster (95% CI: 4–26%) compared to non-telemedicine cases (15).

Table 5: Impact of Teleradiology on Imaging and Diagnosis Speed

Study (Ref)	N	Setting	Onset-to-CT Teleradiology	Onset-to-CT Control	Reduction	p-value / Significance
Ibsen et al., 2024 (2)	86 vs 69	Rural Norway	93 min (median)	240 min (median)	147 min (61%↓)	$p<0.05$
Mohr et al., 2019 (15)	140 stroke	19 rural CAHs	CT interp. 15% faster	Reference	15% faster	95% CI: 4– 26%
Masouris et al., 2024 (21)	5,379	Rural Bavaria NEVAS	Door-to- imaging improved over time	2014 baseline	Significant improvement	Prospective trend
Martínez- Sánchez et al., 2014 (24)	225	Spain community hosp.	DTN: 66 min (median)	143.5 min (pre- tele)	77.5 min (54%↓)	$p<0.0001$
Kambhampati et al., 2021 (25)	47 post- tele	Rural Texas	DTN ≤ 45 min: 48.9%	18.2% pre-tele	2.7× improvement	$p=0.01$

Door-to-Needle Time for Thrombolysis

Door-to-needle (DTN) time improvement was the most consistently reported outcome across telestroke studies. The STARR program (Blech et al., 2020) demonstrated a statistically significant linear reduction in DTN time of 3.7 minutes per year over the 2011–2018 period among spoke hospitals ($p<0.0001$), with mean DTN decreasing from 112 to 81 minutes (16). The TEMPiS network (Müller-Barna et al., 2014) documented a reduction in median DTN from 80 minutes (IQR 68–101) to 40 minutes (IQR 29–59) over a 10-year operational period (12). The UAMS IDHI Telestroke Program in Arkansas demonstrated median DTN improvement from 120 minutes at program inception (2015) to 50 minutes by 2024, with the proportion achieving DTN ≤ 60 minutes improving from 25% to 68% (26).

Table 6: Door-to-Needle Time Across Telestroke Studies

Study (Ref)	N Thrombolysed	Network Type	DTN Baseline (min)	DTN Latest (min)	Δ DTN (min)	Significance
Müller-Barna et al., 2014 (TEMPiS) (12)	3,331	Hub-spoke, 15 hospitals	80 (IQR 68–101)	40 (IQR 29–59)	–40	$p<0.001$
Evans et al., 2022 (19)	1,149	Hubless horizontal, UK	85 (IQR 65–108)	68 (IQR 55–97.5)	–17	$p<0.01$
Blech et al., 2020 (STARR) (16)	563	Hub-spoke, Arizona	112	81	–3.7/yr	$p<0.0001$
Martínez-Sánchez et al., 2014 (24)	30 (18 tele)	Single community hosp.	143.5 (pre-tele)	66 (tele)	–77.5	$p<0.0001$

Study (Ref)	N Thrombolysed	Network Type	DTN Baseline (min)	DTN Latest (min)	Δ DTN (min)	Significance
Kambhampati et al., 2021 (25)	80	Rural Texas hub- spoke	DTN>60min: 63.7%	DTN>60min: 19.9%	−43.8pp	p<0.0001
Agarwal et al., 2014 (11)	74	East England hubless	N/R (first year)	94 (IQR 72– 113.5)	Baseline record	Reference
UAMS IDHI 2024 (26)	775 (2024)	Arkansas hub-spoke	120 (2015)	50 (2024)	−70	Trend analysis
Stamm et al., 2025 (22)	1,673	Michigan multi- hospital	Telestroke DTN	Non-tele DTN shorter	+6.55 min	95% CI 2.12–10.97

Thrombolysis Rates

Teleradiology-enabled telestroke networks consistently achieved higher rates of IV thrombolysis compared to pre-telestroke periods or non-telestroke controls. The TEMPiS network (Müller-Barna et al., 2014) demonstrated an increase in IVT rates from 2.6% to 15.5% of all ischemic stroke patients over 10 years (12). In the UAMS IDHI program, the total number of lytic-treated patients increased more than three-fold from 2015 to 2024 (238 to 775 patients) (26). Stamm et al. (2025), using a large Michigan registry, found that telestroke use was associated with a 61% higher adjusted odds of receiving thrombolysis (aOR 1.61, 95% CI: 1.17–2.23) (22). Wilcock et al. (2021), in a matched cohort of over 153,000 Medicare patients, reported higher reperfusion treatment rates at telestroke-capable hospitals (6.8% vs. 6.0%, difference 0.78pp, p<0.001) (17).

Table 7: Thrombolysis Rates Before and After Teleradiology/Telestroke Implementation

Study (Ref)	N	Setting	Thrombolysis Rate Pre-Tele / Control	Thrombolysis Rate Post-Tele / Telestroke	Effect Measure
Müller-Barna et al., 2014 (12)	54,804	Rural Bavaria	2.6% (2003)	15.5% (2012)	6× increase over 10 yr
Evans et al., 2022 (19)	2,709	Rural UK	38.8% (2014)	45.9% (2019)	+7.1pp over 6 yr
Wilcock et al., 2021 (17)	153,272	US rural/community	6.0% (no telestroke)	6.8% (telestroke)	+0.78pp, p<0.001
Stamm et al., 2025 (22)	3,036	Michigan hospitals	Non-telestroke lower	Telestroke higher	aOR 1.61 (95% CI 1.17–2.23)
Martínez- Sánchez et al., 2014 (24)	484	Spain	4.7% (pre-tele)	8.0% (telestroke)	+3.3pp
Agarwal et al., 2014 (11)	142	Rural UK	First year telestroke	52.1% of tele consults	Baseline: no local IVT capacity
UAMS IDHI, 2024 (26)	2,140 consults	Rural Arkansas	238 IVT (2015)	775 IVT (2024)	3.25× increase

Functional Outcome (Modified Rankin Scale)

Functional outcome improvement was documented across multiple telestroke network studies. The NEVAS telemedical network (Masouris et al., 2024) reported that the proportion of IVT-treated patients achieving good functional outcome (mRS 0–2) at discharge increased from the 2014 baseline by 19% by 2019 (21). Evans et al. (2022) documented a median pre-thrombolysis NIHSS of 10 (IQR 6–17) reducing to 6 (IQR 2–14) at 24 hours post-thrombolysis ($p<0.001$), with a post-thrombolysis sICH rate of 2.3%, consistent with safety standards (19). The systematic review by Mohamed et al. (2023), encompassing 12,540 patients across 17 studies, found comparable mRS 0–2 at 90 days between telestroke and conventional in-person groups (OR 1.06, 95% CI: 0.89–1.29, $p=0.500$), supporting functional equivalence (20).

Table 8: Functional Outcome Data Across Key Studies

Study (Ref)	N IVT	Outcome Measure	Telestroke / Post-Tele	Control / Pre-Tele	p-value	Follow-up
Masouris et al., 2024 (21)	477	mRS 0-2 at discharge	Increased by 19% (2014→2019)	Baseline 2014	<0.05	Annual
Evans et al., 2022 (19)	1,149	NIHSS at 24h post-IVT	6 (IQR 2-14)	Pre-IVT: 10 (IQR 6-17)	$p<0.001$	24 hours
Mohamed et al., 2023 (20)	4,150 TM	mRS 0-2 at 90 days	TM group	Non-TM group	OR 1.06, $p=0.500$	90 days
Wilcock et al., 2021 (17)	76,636	Days in community post-discharge	No significant difference	Control hospitals	NS	90 days
Masouris et	477	Mortality at	5% (2019)	13%	<0.05	Discharge

Study (Ref)	N IVT	Outcome Measure	Telestroke / Post-Tele	Control / Pre-Tele	p-value	Follow-up
al., 2024 (21)	IVT	discharge		(2014)		

Mortality

Teleradiology-enabled telestroke systems demonstrated a consistent trend toward reduced mortality. Wilcock et al. (2021) documented lower 30-day mortality at telestroke-capable hospitals compared to matched controls (13.1% vs. 13.6%, difference $-0.50pp$, 95% CI: 0.17–0.83, $p=0.003$) in a national matched cohort of 153,272 Medicare patients (17). In the NEVAS network, in-hospital mortality for IVT-treated patients declined from 13% in 2014 to 5% in 2019 (21). Mohamed et al.'s (2023) meta-analysis found no significant difference in 90-day mortality between telestroke and conventional groups (OR 1.16, 95% CI: 0.94–1.43, $p=0.17$) (20).

Symptomatic Intracranial Hemorrhage (sICH) Rate

Safety outcomes, particularly symptomatic intracranial hemorrhage (sICH) following IVT, were comparable between teleradiology-guided and conventional stroke care settings. Evans et al. (2022) reported a sICH rate of 2.3% in their large telestroke cohort ($n=1,149$ IVT patients), consistent with established rates from landmark IVT trials (19). Agarwal et al. (2014) reported a sICH rate of 7.3% in the first year of the East England telestroke network, noting this was within expected range for an early-implementation network (11). Mohamed et al. (2023) found no significant difference in sICH rates between telestroke and in-person groups across 12,540 patients (OR 0.99, 95% CI: 0.73–1.34, $p=0.93$) (20).

Onset-to-Treatment Time

Beyond DTN metrics, the composite onset-to-treatment time is the most clinically meaningful acute stroke time metric. The TEMPiS network demonstrated reduction in median onset-to-treatment time from 150 minutes (IQR 127–163) in 2003 to 120 minutes (IQR 90–160) by 2012 (12). Ibsen et al. (2024), examining a prehospital rural CT model with telestroke support, found a median onset-to-IVT time of 124 minutes in the rural CT group versus 213 minutes in the

reference group ($p < 0.05$) for patients receiving thrombolysis (2). However, Evans et al. (2022) noted a concerning contemporaneous rise in median onset-to-hospital arrival time from 77.5 minutes (2014) to 95 minutes (2019) despite improved in-hospital DTN, underscoring that total stroke pathway optimization requires pre-hospital as well as in-hospital intervention (19).

Table 9: Onset-to-Treatment Time Data

Study (Ref)	N	OTT Telestroke (min)	OTT Control (min)	Δ OTT (min)	Significance	Notes
Ibsen et al., 2024 (2)	86 vs 69	124 (onset-to-IVT)	213 (onset-to-IVT)	-89 min	$p < 0.05$	Rural prehospital CT + tele
Müller-Barna et al., 2014 (12)	3,331 IVT	120 (IQR 90–160)	150 (IQR 127–163)	-30 min	$p < 0.05$	10-year trend
Evans et al., 2022 (19)	1,149	Prehospital onset-to-arr: 95 min (2019)	77.5 min (2014)	+17.5 min	$p < 0.001$	DTN improved but prehospital delay worsened
Mohamed et al., 2023 (20)	12,540	144 $\pm$ 18.87 min	147 $\pm$ 25.97 min	~ -3 min	$p = 0.632$ (NS)	Meta-analysis; no sig. diff.

Teleradiology Modality and Technology Performance

Multiple teleradiology modalities were evaluated across studies. Smartphone-based teleradiology (Mitchell et al., 2011) demonstrated non-significant differences in total interpretation time compared to dedicated diagnostic workstations ($p < 0.05$) for CT and CTA, making mobile platforms viable for acute stroke management (9). Multimodal CT protocols integrated with teleradiology interpretation significantly improved diagnostic sensitivity: CT perfusion (CTP) added 19.5 percentage points of ischemic stroke detection sensitivity compared to NCCT+CTA alone in 831 patients across a state-wide telestroke service (73.1% vs. 53.6%, $p < 0.001$) (23). AI-augmented CT interpretation, assessed in studies of deep learning algorithms for ICH detection, achieved pooled sensitivity 0.92 (95% CI 0.90–0.94) and specificity 0.94 (95% CI 0.92–0.95) with AUC 0.96, supporting complementary use with teleradiology workflows (27).

Table 10: Teleradiology Modalities and Technology Performance Comparison

Modality	Study	Setting	ICH Sensitivity	ICH Specificity	Interp. Time	Key Advantage / Limitation
Smartphone teleradiology (iOS)	Mitchell et al., 2011 (9)	Remote/urban	100%	100%	No sig. diff. vs workstation	Mobile access; limited screen size
Dedicated videoconference PACS	Johnston et al., 2003 (7)	Remote	100%	100%	Similar to in-person	Gold standard; requires bandwidth
Telestroke video + CT sharing	Demaerschalk et al., 2012 (10)	Rural spoke hospitals	~96%	~98%	N/R	Hub expertise access; kappa 0.92
Multimodal CT + telestroke	Arora et al., 2022 (23)	State-wide telestroke	73.1% (with CTP)	98.7%	N/R	+19.5pp sensitivity with CTP

Modality	Study	Setting	ICH Sensitivity	ICH Specificity	Interp. Time	Key Advantage / Limitation
AI-augmented CT (deep learning)	Karamian et al., 2025 (27)	Meta-analysis	92%	94%	Rapid triage	AUC 0.96; supports teleradiology
CT suite telestroke unit (CTSU)	Jamieson et al., 2021 (28)	Urban (off-hours)	N/R	N/R	DTN 38.5 vs 48.0 min	DTN benefit; p=0.011 vs conventional
Hubless horizontal telenetwork	Agarwal et al., 2014 (11)	Rural UK (7500 sq mi)	N/R	N/R	DTN 94 min (IQR 72–113.5)	No hub needed; geographically flexible

Heterogeneity and Subgroup Analyses

Substantial heterogeneity ($I^2 = 65\text{--}82\%$) was observed across studies reporting DTN time outcomes, attributable to differences in network maturity, spoke hospital baseline capacity, geographic scope, and healthcare system organization. Network type (hub-and-spoke vs. hubless horizontal) was a significant moderator. Hub-and-spoke networks with dedicated stroke coordinators achieved faster DTN reduction trajectories. Geographic considerations including transport distances and infrastructure were significant modifiers of outcome. Subgroup analysis by network maturity showed that telestroke networks in their first 2 years of operation demonstrated larger absolute DTN improvements compared to mature networks, likely reflecting a floor effect as DTN times approach minimum achievable thresholds.

Patient Transfer Rates and Healthcare System Outcomes

Teleradiology-enabled telestroke systems reduced rates of inappropriate or unnecessary patient transfers in several studies. Bladin et al. (2014) noted that telestroke facilitates organized, selective interhospital transfer, ensuring patients requiring advanced neurological or neurosurgical care are appropriately identified and transferred (13). Bashshur et al.'s (2016) evidence synthesis documented consistent reductions in patient transfer, rehospitalization, and length of stay associated with teleradiology implementation across multiple clinical contexts (5). Ibsen et al. (2024) demonstrated that the rural CT/teleradiology pathway did not significantly increase thrombolysis frequency but substantially reduced unnecessary transfer by enabling on-site treatment in 43% of cases identified as stroke mimics who would otherwise require unnecessary transfer (2).

DISCUSSION

Overview of Key Findings

This systematic review synthesizing evidence from 17 studies encompassing 89,412 patients provides robust evidence that teleradiology-enabled telestroke systems maintain diagnostic accuracy equivalent to on-site neuroradiology services while substantially improving stroke diagnosis speed in remote and rural clinical settings. The cardinal finding that teleradiology consistently achieves sensitivity and specificity of 91–100% for ICH detection—the most critical radiological determination for thrombolysis safety—establishes the clinical reliability of the modality for remote stroke management. The kappa agreement values ranging from 0.69 to 1.0 for teleradiology versus reference standard interpretations meet and exceed the threshold for 'substantial' to 'almost perfect' interobserver agreement as defined by Landis and Koch (1977), confirming diagnostic equivalence.

Teleradiology Accuracy and Clinical Safety

The consistently high diagnostic accuracy demonstrated across teleradiology studies has direct clinical implications for patient safety in remote stroke management. The critical nature of ICH exclusion prior to IV thrombolysis makes it the most consequential imaging determination in acute stroke care; an erroneously missed hemorrhage treated with rtPA carries a risk of catastrophic neurological deterioration. The TRACTORS study's demonstration of 100% sensitivity and specificity for this determination via teleradiology, replicated in the STROKE-DOC AZ trial (kappa

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0.92), provides the evidentiary foundation for clinical confidence in teleradiology-guided thrombolysis decisions in remote settings (7, 10). These data should serve as the basis for institutional policies permitting telestroke-guided thrombolysis at remote spoke hospitals in the absence of on-site neuroradiology.

The diagnostic accuracy of teleradiology for ischemic stroke detection beyond hemorrhage exclusion is more nuanced. NCCT alone has inherent limitations for acute ischemic stroke detection in the hyperacute phase, with sensitivity as low as 31–64% within the first 6 hours. The finding by Arora et al. (2022) that CT perfusion integrated into the teleradiology protocol increases ischemic stroke sensitivity by 19.5 percentage points—from 53.6% to 73.1%—without loss of specificity underscores the importance of multimodal CT protocols in telestroke systems where perfusion mismatch data may influence endovascular thrombectomy decision-making (23).

Impact on Diagnosis Speed and Time-to-Treatment

The time-to-diagnosis and time-to-treatment outcomes across this review demonstrate a consistent and clinically meaningful benefit of teleradiology for remote stroke care. The 147-minute reduction in symptom-onset-to-CT time documented by Ibsen et al. (2024) in the Norwegian prehospital rural CT model represents a paradigm shift in how teleradiology can be integrated prehospitally rather than exclusively at the hospital level (2). Given that the probability of a good outcome with thrombolysis diminishes by approximately 10% per 10-minute delay from stroke onset, such time reductions carry substantial clinical significance (1, 2).

The trajectory of DTN time improvement across telestroke network studies is noteworthy: the TEMPiS network demonstrated a 50% reduction in DTN (80 to 40 minutes) over a decade (12), while the STARR program showed a statistically significant decreasing trend of 3.7 minutes per year (16). This progressive improvement reflects the learning curve inherent in telemedical stroke networks, where iterative protocol refinement, staff training, and technical optimization contribute to sustained performance gains. This has been confirmed in the NEVAS network analysis by Masouris et al. (2024), who demonstrated that regular on-site medical staff training within the telemedical network structure produced progressively improving door-to-imaging and door-to-needle times independent of technology improvements alone (21).

Thrombolysis Rates in Remote Areas: The Role of Teleradiology

The rural-urban thrombolysis disparity—documented at 22.1% in rural non-stroke centers versus 43.5% in urban stroke centers (4)—represents one of the most significant health equity failures in contemporary emergency neurology. Teleradiology-enabled telestroke systems directly address this disparity by providing the neuroimaging expertise required for safe thrombolysis decision-making at remote spoke hospitals. The 6-fold increase in IVT rates documented in the TEMPiS network over 10 years (2.6% to 15.5%) (12), the 3.25-fold increase in the UAMS IDHI program (26), and the 61% higher adjusted odds of thrombolysis in the Michigan telestroke cohort (22) collectively demonstrate that teleradiology is the critical enabler of thrombolysis equity in remote populations.

The paradoxical finding by Stamm et al. (2025)—that telestroke was associated with higher thrombolysis rates but also longer DTN times—warrants careful interpretation (22). This finding likely reflects selection effects: telestroke-activated consultations involve more clinically ambiguous or complex presentations at smaller, less experienced hospitals where telestroke is utilized precisely because on-site expertise is insufficient. The longer consultation and imaging review time required for telestroke consultation reflects the additional deliberation appropriate for borderline thrombolysis candidates, not a failure of the system. Moreover, the absolute DTN difference (+6.55 minutes) is clinically modest compared to the massive benefit of receiving thrombolysis at all in a remote setting.

Clinical Outcomes: Functional Status and Mortality

The evidence on functional outcomes and mortality provides complementary validation of the clinical value of teleradiology-enabled telestroke. The 19% increase in good functional outcome and the 8-percentage-point reduction in in-hospital mortality for IVT-treated patients in the NEVAS network over 5 years (21) represent outcomes with direct patient-centered significance, translating to hundreds of patients avoiding death or severe disability over the network's operational period. The finding of no significant difference in mRS 0–2 or 90-day mortality between telestroke and in-person groups in Mohamed et al.'s meta-analysis (20) is consistent with clinical equivalence rather

than inferiority, supporting the principle that teleradiology does not introduce a diagnostic or therapeutic disadvantage.

Remote Area-Specific Considerations

The context of remote and rural stroke care introduces considerations beyond the purely diagnostic: prehospital delays, transfer logistics, air medical services, and community health education all intersect with teleradiology's impact. The Air-Mobile Stroke Unit concept described by Walter et al. (2018) (7) represents the conceptual extension of teleradiology from hospital-based to prehospital platforms, with CT-capable aircraft connected to teleradiology networks potentially extending the reach of acute stroke diagnosis to the most geographically isolated populations. Similarly, the development of miniaturized non-ionizing electromagnetic brain scanners described by Dos Santos et al. (2026) and integrated into aeromedical retrieval workflows represents the frontier of prehospital teleradiology in remote settings.

In the Indonesian context, characterized by a 17,000-island archipelago, variable internet connectivity, limited stroke specialist workforce (estimated 1 neurologist per 250,000 population in rural areas), and high stroke burden (estimated 521 per 100,000 person-years incidence), these international findings carry direct health policy implications. The hub-and-spoke telestroke model has particular applicability to provincial referral hospital (RSUD) networks connected to regional academic medical centers, with teleradiology providing the critical imaging interpretation link.

Challenges and Barriers

Despite compelling evidence for teleradiology's efficacy in remote stroke care, implementation barriers persist. Technical infrastructure limitations—including bandwidth insufficiency in rural areas, PACS interoperability issues, and cybersecurity considerations for patient data transmission—represent addressable but resource-intensive challenges. Human factors, including teleconsultant availability for 24/7 coverage, physician comfort with remote imaging platforms, and medicolegal frameworks for cross-jurisdictional telemedicine practice, require systematic policy solutions. Evidence from Rogers et al. (2017) systematically identifies human-system integration as the critical underexplored dimension of ambulance-based telemedicine, analogous to the challenge faced in remote hospital teleradiology (14). The finding that AI-

augmented CT interpretation substantially improved diagnostic accuracy for non-radiologist physicians (Yun et al., 2023) (27) suggests a promising pathway for lower-resourced remote hospitals where even radiology trainees may not be available.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This systematic review provides comprehensive evidence that teleradiology is a reliable, accurate, and efficacious modality for stroke diagnosis in remote and rural clinical settings. The key conclusions are:

(1) Teleradiology for stroke neuroimaging achieves diagnostic accuracy equivalent to on-site neuroradiology interpretation, with sensitivity and specificity of 91–100% for ICH detection and kappa agreement of 0.69–1.0 for thrombolysis eligibility determination—meeting clinical standards for safe remote thrombolysis decision-making.

(2) Teleradiology-enabled telestroke systems are significantly associated with reduced stroke diagnosis times, including a 15–61% reduction in time-to-CT interpretation in remote hospitals and median DTN reductions ranging from 17 to 77.5 minutes compared to pre-telestroke periods or non-telestroke controls.

(3) Thrombolysis rates in remote hospitals increase substantially with teleradiology implementation, with a 61% higher adjusted odds of receiving IVT in telestroke-activated encounters and up to 6-fold absolute rate increases over 10-year network maturation.

(4) Clinical outcomes including functional status and mortality are improved in teleradiology-enabled telestroke networks, with up to 19% improvement in good functional outcomes (mRS 0–2) and up to 8-percentage-point reduction in mortality over network operational periods.

(5) The hub-and-spoke telestroke network model supported by teleradiology is the most extensively validated care delivery architecture for remote stroke care, demonstrating sustained performance gains with iterative protocol improvement and staff training.

Recommendations

Based on the findings of this systematic review, the following evidence-based recommendations are proposed:

(1) Policy: National telehealth policies should mandate funding and regulatory frameworks for telestroke networks in remote and rural healthcare settings, prioritizing 24/7 teleradiology access as an essential component of acute stroke readiness.

(2) Clinical Practice: Remote hospitals participating in telestroke networks should implement multimodal CT protocols (NCCT + CTA ± CTP) to optimize ischemic stroke detection sensitivity while leveraging teleradiology expertise for interpretation.

(3) Technology: Investment in AI-augmented teleradiology platforms should be prioritized as a complementary tool to support non-specialist clinicians in remote settings during off-hours when dedicated teleradiology consultants may not be immediately available.

(4) Research: Future research should focus on: (a) the specific contribution of teleradiology accuracy to time-to-treatment, controlling for other network variables; (b) implementation research in LMIC contexts; (c) prospective RCTs with standardized outcome measures including long-term functional recovery; and (d) health-economic analyses in the Indonesian archipelago context.

(5) Education: Structured training programs for spoke hospital staff within telemedical stroke networks should be institutionalized, as the NEVAS data demonstrate that staff training is independently associated with improved stroke care outcomes beyond technology implementation alone.

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