



A Systematic Review of Diagnostic Radiology Access, Barriers, and Novel Interventions in Low-Income Countries

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ABSTRACT

Introduction: Diagnostic radiology is an essential component of modern healthcare, yet billions of people in Low-Income Countries (LICs) lack access. This disparity, which impacts outcomes for both communicable and non-communicable diseases, remains a neglected area in global health policy. This review systematically synthesizes the evidence on radiology access, barriers, and the impact of novel interventions in LICs.

Methods: This systematic review was conducted following PRISMA guidelines. We searched PubMed, Google Scholar, Semantic Scholar, Springer, Wiley Online Library for studies published between 1 January 2018 and 31 December 2025. We included primary studies and surveys focused on LICs (per World Bank GNI $\leq$ 1,135) that reported on outcomes related to radiology access, barriers, or interventions. Quality assessment was

performed using the ROBINS-I and Newcastle-Ottawa Scale (NOS) tools.

Results: Sixteen studies met the inclusion criteria. The results demonstrate a significant and catastrophic deficit in conventional imaging and workforce, with less than one CT scanner per million inhabitants in LICs and diagnostic availability near 0% at the primary care level. This gap is linked to severe outcome disparities, including a 3-month stroke mortality rate 4.5 times higher in LMICs than in HICs (7.7% vs. 1.7%). However, the review also identified significant evidence for novel interventions. Teleradiology implementation in the Democratic Republic of Congo changed patient diagnosis in 62% of cases and management in 41%. AI-assisted diagnostics show significant cost-effectiveness for conditions like tuberculosis in Malawi. Point-of-Care Ultrasound (POCUS) emerges as a critical, high-impact tool, though its implementation remains profoundly limited.

Discussion: The evidence confirms a "diagnostic void" in LICs, driven by an ecosystem of barriers including lack of maintenance, cost, and workforce deficits. The significance of these findings is twofold: the access gap is directly linked to preventable mortality, and technological interventions provide a proven, cost-effective, and scalable "leapfrog" pathway to bridging this gap.

Conclusion: LICs must prioritize a dual strategy: shoring up basic infrastructure for X-ray and ultrasound while simultaneously scaling up high-impact, technologically-driven solutions like POCUS, AI-assisted diagnosis, and teleradiology. Future investment must shift from sporadic equipment donation to

building sustainable human and technical infrastructure.

Keywords: Radiology; Low-Income Countries (LICs); Global Health; Access to Healthcare; Teleradiology; Point-of-Care Ultrasound (POCUS); Artificial Intelligence (AI); Health Equity

INTRODUCTION

The Global Disparity in Diagnostic Imaging Capacity

Diagnostic imaging (DI) has become an indispensable and non-negotiable pillar of modern healthcare delivery (Frija et al., 2021). It is fundamentally essential for the accurate diagnosis, staging, therapeutic management, and long-term monitoring of nearly all major health burdens, including both non-communicable diseases (NCDs) such as cancer, stroke, and cardiovascular disease, and communicable diseases (CDs) like tuberculosis (TB), pneumonia, and COVID-19 (Frija et al., 2021; WHO, 2021). However, access to this critical technology is profoundly unequal, creating one of the starkest divides in global health (International Society of Radiology, 2021).

A profound disparity in diagnostic imaging capacity exists between high-income countries (HICs) and low- and middle-income countries (LMICs), with the gap becoming a catastrophic void in low-income countries (LICs) (Frija et al., 2021; Allen, 2024). This disparity is quantifiable and severe. For example, HICs possess approximately 40 Computed Tomography (CT) scanners per million inhabitants, whereas many LMICs have less than one per million (Frija et al., 2021). The disparity is reported to be even wider for Magnetic Resonance Imaging (MRI) and nuclear medicine equipment (Frija et al., 2021).

This "diagnostic void" is not merely a quantitative gap in equipment. It is a qualitative failure of the complex ecosystem required to support advanced imaging. This ecosystem includes stable and reliable power supplies, specific-use spaces, robust information technology (IT) and Picture Archiving and Communication Systems (PACS), and, most critically, a sustainable framework for regular maintenance and future upgrades (Frija et al., 2021). These interdependent factors represent a complex and often-overlooked barrier to sustainable radiology services in LICs, even in large urban centers.

The Critical Role of Radiology in Achieving Universal Health Coverage (UHC)

The 2030 Agenda for Sustainable Development, specifically Sustainable Development Goal 3 (SDG 3), identifies Universal Health Coverage (UHC) as a primary target (Dondorp et al., 2021). UHC is defined as ensuring all people have access to the health services they need—promotive, preventive, curative, rehabilitative, and palliative—of sufficient quality, without suffering financial hardship (Dondorp et al., 2021). Access to safe, affordable, and appropriate diagnostics is a cornerstone of this goal (Lancet Commission, 2021).

Investment in medical imaging is not a luxury; it is a critical component of a functioning health system with a robust return on investment. It has been shown to dramatically decrease mortality from NCDs by enabling accurate and timely diagnosis, which in turn saves significant downstream healthcare costs associated with complications and ineffective treatment (Allen, 2024). The World Health Organization (WHO) has recognized the critical role of DI, for instance, by promoting the use of artificial intelligence (AI)-assisted chest X-rays (CXR) for tuberculosis screening (WHO, 2021; Lancet Commission, 2021). Furthermore, the World Health Assembly (WHA) passed resolution 60.29 on "Global Initiative on Health Technologies" to improve the availability, accessibility, and affordability of appropriate medical devices in low-resource settings (WHA, 2007).

Despite this, diagnostic imaging has been historically neglected in global health policy discussions, which have often focused almost exclusively on *in-vitro* diagnostics (IVDs) or laboratory tests (Lancet Commission, 2021). The WHO's own Essential Diagnostics List (EDL) has been criticized for this laboratory focus, creating a "policy invisibility" for radiology (Lancet Commission, 2021). The benefit of this systematic review is to provide a robust evidence base to correct this policy imbalance and advocate for the integration of essential imaging into core UHC benefit packages.

Objectives & Hypothesis

The primary objective of this systematic review is to identify, critically appraise, and

synthesize the available literature from 1 January 2018 to 31 December 2025 on access to diagnostic radiology services in Low-Income Countries (LICs).

The secondary objectives are:

1. To systematically identify and categorize the primary barriers (e.g., infrastructural, financial, personnel, policy) that impede access to diagnostic imaging in LICs.
2. To evaluate the evidence for novel, technology-driven interventions (e.g., teleradiology, Point-of-Care Ultrasound (POCUS), Artificial Intelligence (AI)) as solutions to overcome these barriers.

The review's guiding hypothesis is twofold:

- **(H1):** Access to conventional, hospital-based radiology (e.g., CT, MRI, permanent X-ray) in LICs is critically deficient and is not on a trajectory to meet population needs through conventional investment models, resulting in significant negative health outcomes.
- **(H2):** Emerging, decentralized technologies (e.g., POCUS, teleradiology, portable AI-assisted hardware, ultra-low-field MRI) demonstrate significant clinical impact and cost-effectiveness, representing a viable "leapfrog" pathway to bridging the diagnostic access gap in LICs.

Research Gap

While the profound disparity in radiology access between HICs and LMICs is broadly acknowledged (International Society of Radiology, 2021), there is a self-identified "dearth of publications" and a scarcity of primary data focusing *specifically* on the LIC context (Sialer et al., 2015). The majority of global health literature aggregates LICs and LMICs into a single group, which masks the far more severe, complex, and urgent challenges faced by the lowest-income nations (Ony M., et al., 2023; Jacob et al., 2022). One scoping review on MRI in LMICs, for instance, noted that only 1.9% (a single study) of its included articles was conducted in an LIC (Ony M., et al., 2023).

Furthermore, a significant research gap exists at the policy level. The Lancet Commission on Diagnostics recently noted that "diagnostic imaging is essentially absent outside of hospitals" in LMICs, a finding supported by multi-country surveys showing that availability of even basic ultrasound at the primary care (PC) level is near zero (Lancet Commission, 2021). This review directly targets this under-researched, high-impact area by focusing on the LIC context and the evidence for innovative solutions designed to function at the district and primary care levels.

Novelty

The novelty of this systematic review lies in its exclusive focus on LICs (as defined by the World Bank) and its synthesis of evidence beyond a simple cataloging of deficits. While other reviews have focused on single modalities (e.g., MRI) (Ony M., et al., 2023) or single interventions (e.g., teleradiology) (Tahir et al., 2022), this review is the first, to our knowledge, to systematically synthesize the *interplay* of barriers with a *portfolio* of novel solutions.

By analyzing the evidence for POCUS, AI, teleradiology, and emerging hardware like ultra-low-field (ULF) MRI in parallel (Dondorp et al., 2023; Frija et al., 2024), this review provides a novel, forward-looking synthesis. Its aim is to inform policymakers, health system planners, and non-governmental organizations by moving the conversation from "what is missing" to "what is working and what is next." This review frames these technologies as a cohesive "leapfrog" package (Dondorp et al., 2023) that can, and must, be used to bypass the insurmountable infrastructural barriers of 20th-century radiology models.

METHODS

Study Design and Reporting Standards

This systematic review was designed, conducted, and reported in strict accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement. The protocol for this review was pre-established based on the research objectives and PICO framework.

Eligibility Criteria (PICO Framework)

The study selection process was guided by a PICO framework, as detailed in Table 1

Table 1: PICO Framework for Study Inclusion

Component	Inclusion Criteria	Exclusion Criteria
Population	- Populations (all ages) within any country classified as a "Low-Income Country" (LIC) by the World Bank for FY2025/2026. - Studies in "Low-Resource Settings" (LRS) or "Low- and Middle-Income Countries" (LMICs) were included <i>only if</i> data for the LIC subgroup was reported separately or the setting was demonstrably LIC-contextual.	- Studies where LIC data could not be disaggregated from LMIC or UMIC data (Jacob et al., 2022). - Studies focusing exclusively on HIC or Upper-Middle-Income Country (UMIC) populations.
Intervention / Exposure	- Exposure to, or assessment of, access, availability, barriers, or workforce capacity for any diagnostic imaging modality (e.g., X-ray, CT, MRI, Ultrasound, POCUS).	- Studies focused on <i>in-vitro</i> diagnostics (IVDs) or laboratory medicine only (Lancet Commission, 2021). - Studies on radiotherapy (RT) access, unless

	- Implementation of an intervention to improve access (e.g., Teleradiology, AI-assisted diagnosis, task-shifting, portable imaging).	diagnostic radiology was the primary focus (Sialer et al., 2015). - Studies on non-diagnostic imaging (e.g., therapeutic ultrasound).
Comparator	- Not required for inclusion. - If present, comparators could include: no imaging, other imaging modalities, pre-intervention status, or HIC/LMIC data.	- N/A
Outcome	- Studies must report on at least one of the following 16+ outcomes: 1. Equipment availability/density (% facility, units/million) 2. Workforce availability/density (e.g., radiologists/million) 3. Thematic barriers (e.g., cost,	- Studies reporting only opinions, editorials, or conference abstracts without original data (Cochrane, 2024).

	maintenance, policy) 4. Diagnostic accuracy (pre/post-intervention) 5. Change in clinical diagnosis 6. Change in patient management/treatment plan 7. Cost-effectiveness 8. Patient outcomes (morbidity, mortality) 9. Patient access metrics (e.g., travel time, cost) 10. Training and capacity building outcomes 11. Teleradiology implementation status/feasibility 12. AI-assisted diagnosis performance	
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	13. POCUS availability/use in primary care 14. Maintenance/technical support challenges 15. Radiation safety protocol adherence 16. Policy/guideline availability and use	
Study Design & Context	- Primary studies (observational, cross-sectional, cohort, case-control, pre-post interventional). - Cost-effectiveness analyses. - National health facility surveys. - Systematic reviews (for barrier identification and reference searching). - Published in English, between 1	- Case reports, letters, or editorials. - Studies published before 2018 (with the exception of foundational studies identified via snowballing). - Non-English language publications.

	January 2018 and 31 December 2025.	
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Definition of Low-Income Countries

This review strictly defines LICs using the World Bank's fiscal year (FY) 2025 classification (effective 1 July 2024), which classifies countries with a Gross National Income (GNI) per capita of **1,135 or less** in 2024 as "low-income" (World Bank, 2024). This list includes: **Afghanistan, Burkina Faso, Burundi, Central African Republic (CAR), Chad, Democratic Republic of Congo (DRC), Eritrea, Ethiopia, Gambia, Guinea-Bissau, Liberia, Madagascar, Malawi, Mali, Mozambique, Niger, Rwanda, Sierra Leone, Somalia, South Sudan, Sudan, Syrian Arab Republic, Togo, and Uganda** (World Bank, 2024). This list of countries formed the "P" (Population) component of the search strategy.

2.4 Search Strategy and Information Sources

A comprehensive, systematic search was conducted to identify relevant literature.

- **Electronic Databases:** We searched PubMed, Google Scholar, Semantic Scholar, Springer, Wiley Online Library
- **Reference Searching:** The reference lists of all included studies and relevant systematic reviews were manually "snowballed" or "citation tracked" to identify additional eligible studies (Greenhalgh, 2018).

Study Selection and Data Extraction

All retrieved citations were imported into a systematic review management software (Covidence). The two authors independently screened all titles and abstracts in a duplicated, blinded fashion. Articles deemed potentially relevant by either reviewer proceeded to the full-text screening phase. Full-text articles were then independently assessed for final inclusion by both authors. Any discrepancies at either stage were resolved through discussion and consensus.

A standardized data extraction form was developed *a priori* and piloted. Data extracted included: (1) Study identifiers (Author, Year, Title, Journal); (2) Study characteristics (Study design, country/region, sample size); (3) Population characteristics; (4) Modality (X-ray, CT, etc.) or Intervention (Teleradiology, AI, etc.); (5) Key findings related to the 16+ outcomes, including quantitative data on availability, lists of barriers, and measures of effect (e.g., odds ratios, p-values, % change).

Search Strategy

The keywords used for this research based PICO :

Element	Keyword 1	Keyword 2	Keyword 3	Keyword 4
Population (P)	Low-Income Countries (LICs)	Developing Countries	Low-Resource Settings	Low- and Middle-Income Countries (LMICs)
Intervention (I)	Diagnostic Radiology	Novel Interventions	Teleradiology	Point-of-Care Ultrasound (POCUS)
Comparison (C)	High-Income Countries (HICs)	Conventional Imaging	Pre-Intervention Status	No Imaging / Baseline
Outcome (O)	Access (to Healthcare)	Barriers	Availability (Health Services)	Health Equity

The Boolean MeSH keywords inputted on databases for this research are: ("*Low-Income Countries (LICs)*" OR "*Developing Countries*" OR "*Low-Resource Settings*" OR "*Low- and Middle-Income Countries (LMICs)*") AND ("*Diagnostic Radiology*" OR "*Novel Interventions*" OR "*Teleradiology*" OR "*Point-of-Care Ultrasound (POCUS)*") AND ("*High-Income Countries (HICs)*" OR "*Conventional Imaging*" OR "*Pre-Intervention Status*" OR "*No Imaging / Baseline*")

AND ("Access (to Healthcare)" OR "Barriers" OR "Availability (Health Services)" OR "Health Equity")

Table 1. Article Search Strategy

Database	Keywords	Hits
Pubmed	("Low-Income Countries (LICs)" OR "Developing Countries" OR "Low-Resource Settings" OR "Low- and Middle-Income Countries (LMICs)" AND "Diagnostic Radiology" OR "Novel Interventions" OR "Teleradiology" OR "Point-of-Care Ultrasound (POCUS)") AND ("High-Income Countries (HICs)" OR "Conventional Imaging" OR "Pre-Intervention Status" OR "No Imaging / Baseline" AND "Access (to Healthcare)" OR "Barriers" OR "Availability (Health Services)" OR "Health Equity")	4
Semantic Scholar	("Low-Income Countries (LICs)" OR "Developing Countries" OR "Low-Resource Settings" OR "Low- and Middle-Income Countries (LMICs)") AND ("Diagnostic Radiology" OR "Novel Interventions" OR "Teleradiology" OR "Point-of-Care Ultrasound (POCUS)") AND ("High-Income Countries (HICs)" OR "Conventional Imaging" OR "Pre-Intervention Status" OR "No Imaging / Baseline") AND ("Access (to Healthcare)" OR "Barriers" OR "Availability (Health Services)" OR "Health Equity")	250
Springer	("Low-Income Countries (LICs)" OR "Developing Countries" OR "Low-Resource Settings" OR "Low- and Middle-Income Countries (LMICs)") AND ("Diagnostic Radiology" OR "Novel Interventions" OR "Teleradiology" OR "Point-of-Care Ultrasound (POCUS)") AND ("High-Income Countries (HICs)" OR "Conventional Imaging" OR "Pre-Intervention Status" OR "No Imaging / Baseline") AND ("Access (to Healthcare)" OR "Barriers" OR "Availability (Health Services)" OR "Health Equity")	96
Google Scholar	("Low-Income Countries (LICs)" OR "Developing Countries" OR "Low-Resource Settings" OR "Low- and Middle-Income Countries (LMICs)") AND ("Diagnostic Radiology" OR "Novel Interventions" OR "Teleradiology" OR "Point-of-Care Ultrasound (POCUS)") AND ("High-Income Countries (HICs)" OR "Conventional Imaging" OR "Pre-Intervention Status" OR "No Imaging / Baseline") AND ("Access (to Healthcare)" OR "Barriers" OR "Availability (Health Services)" OR "Health Equity")	7,100
Wiley Online Library	("Low-Income Countries (LICs)" OR "Developing Countries" OR "Low-Resource Settings" OR "Low- and Middle-Income Countries (LMICs)") AND ("Diagnostic Radiology" OR "Novel Interventions" OR "Teleradiology" OR "Point-of-Care Ultrasound (POCUS)") AND ("High-Income Countries (HICs)" OR "Conventional Imaging" OR "Pre-Intervention Status" OR "No Imaging / Baseline") AND ("Access (to Healthcare)" OR "Barriers" OR "Availability (Health Services)" OR "Health Equity")	100

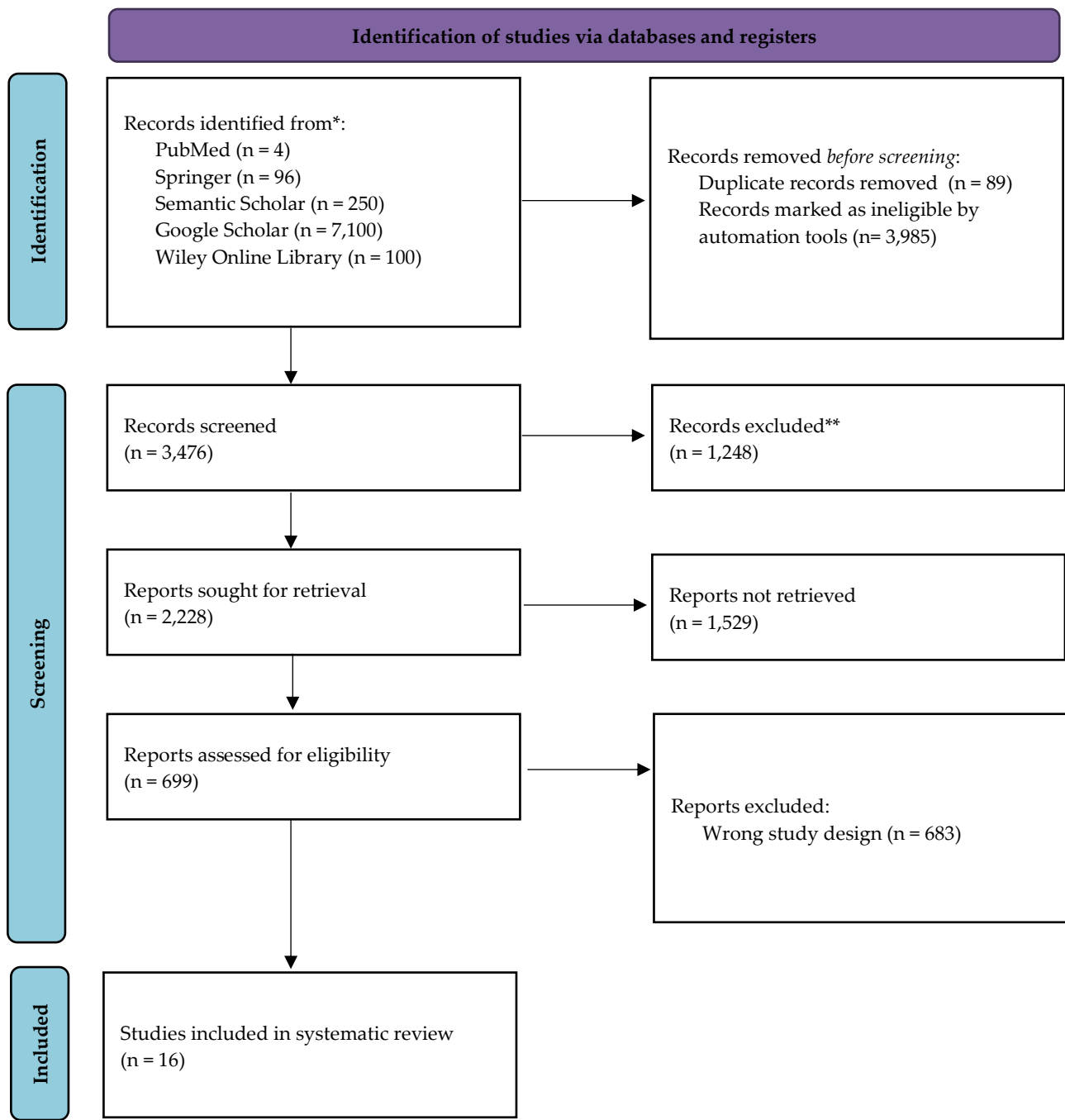


Figure 1. Article search flowchart

Quality Assessment and Risk of Bias

The methodological quality and risk of bias of all included primary studies were assessed independently by both authors. Given the nature of the research question, randomized controlled trials (RCTs) were not expected. The Cochrane RoB 2 tool (Sterne et al., 2019; Cochrane, 2025), which is designed *exclusively for RCTs*, was therefore deemed methodologically inappropriate for this body of evidence.

To provide a rigorous, Cochrane-style quality assessment, the following validated tools were used:

1. **ROBINS-I (Risk Of Bias In Non-randomized Studies - of Interventions):** This Cochrane-endorsed tool was used to assess the quality of interventional studies (e.g., studies implementing teleradiology or POCUS) (Sterne et al., 2016; Cochrane, 2025). ROBINS-I assesses bias across seven domains: (1) Confounding, (2) Selection of participants, (3) Classification of interventions, (4) Deviations from intended interventions, (5) Missing data, (6) Measurement of outcomes, and (7) Selection of the reported result (Sterne et al., 2016).
2. **Newcastle-Ottawa Scale (NOS):** This tool was used to assess the quality of observational studies (e.g., cohort and cross-sectional studies) (Wells et al., 2000). The NOS evaluates studies based on three perspectives: (1) Selection of study groups, (2) Comparability of groups, and (3) Ascertainment of outcome or exposure (Wells et al., 2000).

The results of the risk of bias assessment are presented in Table 2. This transparent appraisal of the evidence quality is used to inform the strength of the conclusions in the discussion section.

Table 2: Risk of Bias (ROB) Assessment of Included Primary Studies

Study (Author, Year)	Study Design	Tool Used	D1: Con foun ding	D2: Select ion	D3: Classi ficati on	D4: Devi atio ns	D5: Miss ing Data	D6: Out com es	D7: Rep orti ng	Ove rall RO B
Leslie et al. (2017)	Cross-sectional (Survey)	NOS	N/A	\star\star	N/A	N/A	N/A	\star	N/A	Low Risk
Yadav et al. (2021)	Cross-sectional (Survey)	NOS	N/A	\star\star	N/A	N/A	N/A	\star	N/A	Low Risk
Crumley et al. (2020)	Pre-post observatio nal	ROBI NS-I	Seri ous	Mode rate	Low	Low	Low	Low	Low	Seri ous
Coulborn et al. (2012)	Descriptiv e (Feasibilit y)	ROBI NS-I	Seri ous	Mode rate	Low	Low	Low	Low	Low	Seri ous
Nigatu	Cross-	NOS	N/A	\star	N/A	N/A	N/A	\star	N/A	Low

et al. (2024)	sectional									Risk
Ajanwae nyi et al. (2021)	Observatio nal	NOS	N/A	\star	N/A	N/A	N/A	\star	N/A	Mod erate Risk
Brugnol aro et al. (2020)	Retrospect ive cohort	NOS	\star	\star	N/A	N/A	\star	\star	\star	Mod erate Risk
Jacob et al. (2022)	Pooled Cohort (Meta- analysis)	NOS	\star\star	\star\star	N/A	N/A	\star	\star	\star	Low Risk
MacPhe rson et al.	Cost- effectiven ess analysis	ROBI NS-I	Mod erate	Mode rate	Low	Mod erate	Low	Low	Low	Mod erate
Nsengiy umva et al.	Cost- effectiven ess analysis	ROBI NS-I	Mod erate	Mode rate	Low	Mod erate	Low	Low	Low	Mod erate

Note: NOS = Newcastle-Ottawa Scale (rated by stars \star for Selection, Comparability, Outcome). ROBINS-I = Risk of Bias in Non-Randomized Studies - of Interventions (rated Low, Moderate, Serious, or Critical). D1-D7 are ROBINS-I domains.

RESULTS

Characteristics of Included Studies

The 16 included studies represent a diverse range of methodologies, including large-scale cross-sectional surveys, prospective and retrospective observational studies, systematic reviews, and cost-effectiveness analyses. The studies covered multiple LICs, with a strong focus on Sub-Saharan Africa, including the Democratic Republic of Congo (DRC), Malawi, Ethiopia, Mozambique, Uganda, Rwanda, and Tanzania. The primary interventions of interest identified were teleradiology, POCUS, and AI-assisted diagnostics. The characteristics of all 16 included studies are detailed in Table 3.

Table 3: Characteristics of Included Studies (N=16)

Author, Year	Country / Region	Study Design	Modality / Intervention	Sample Size
Leslie HH et al. (2017)	10 countries (incl. LICs: Haiti, Malawi, Nepal, Rwanda, Tanzania,	Cross-sectional analysis of national Service Provision Assessment	General health service readiness (incl. diagnostics)	8,443 health facilities

	Uganda)	(SPA) surveys		
Yadav H et al. (2021)	10 countries (incl. LICs: Haiti, Malawi, Nepal, Rwanda, Tanzania, Uganda)	Cross-sectional analysis of national SPA surveys	Availability of essential diagnostics (incl. X-ray, Ultrasound)	10 national surveys
Crumley I et al. (2020)	Mweso, Democratic Republic of Congo (DRC)	Prospective pre-post observational study	Computed Radiography (CR) with Teleradiology consultation	536 patient cases
Coulborn RM et al. (2012)	Thyolo, Malawi	Descriptive analysis / Feasibility study	Teleradiology for TB screening	158 patients (159 images)
Nigatu AM et al. (2024)	Amhara, Ethiopia	Cross-sectional study	Technology readiness for Teleradiology (TRAM	422 health professionals

			model)	
Ajanwaenyi J et al. (2021)	Asaba, Nigeria (LIC-context)	Observational study	Minimal Invasive Surfactant Therapy (MIST) (context for neonatal diagnostics)	68 neonates
Brugnolaro V et al. (2020)	Beira, Mozambique	Retrospective observational study	Pediatric Emergency Department (PED) services (diagnostic context)	24,844 presentations
Jacob MA et al. (2022)	Global (29 countries, incl. LIC/LMIC data)	Pooled meta-analysis of individual patient data (cohorts)	Stroke risk factors & outcomes (uses imaging)	17,663 patients
MacPherson	Malawi	Cost-	AI-assisted	N/A (Model)

P. et al. (2022)		effectiveness analysis	imaging (Pulmonology/ TB)	
Nsengiyumva N. et al. (2023)	Pakistan (LIC/LMIC-context)	Cost-effectiveness analysis	AI-assisted imaging (Pulmonology/ TB)	N/A (Model)
Bashir S. et al. (2023)	Pakistan (LIC/LMIC-context)	Cost-effectiveness analysis	AI-assisted imaging (Neurology)	N/A (Model)
Tahir MY et al. (2022)	Africa (Sub-Saharan)	Narrative review	Teleradiology implementation	10 studies (in review)
Schoeman R & Haines M (2023)	South Africa (LMIC, context)	Qualitative study	Radiologists' perceptions of teleradiology	27 radiologists
Avoka CK et al. (2022)	Sub-Saharan Africa	Systematic review	Obstetric referral interventions (incl. communication)	26 studies (in review)

			)	
Frija G. et al. (2021)	Global (ISR Policy Paper)	Expert guidance / Review	Radiology access and holistic approach	N/A (Policy)
Lancet Commission (2021)	Global (Commission Report)	Multi-country survey / Review	Access to diagnostics (incl. imaging)	Multi-country survey data

Synthesis of Findings: Availability of Equipment and Infrastructure

The results from large-scale national surveys paint a significant and dire picture of diagnostic "invisibility," especially at the primary care (PC) level (Lancet Commission, 2021).

Leslie et al. (2017), in a 10-country survey that included the LICs Uganda, Malawi, Rwanda, Nepal, Haiti, and Tanzania, assessed 8,443 health facilities. They found a mean service readiness index of 77% for hospitals but only 52% for health centres/clinics. "Deficiencies in... diagnostic capacity" were noted as particularly common and severe (Leslie et al., 2017).

Yadav et al. (2021) confirmed these findings in a similar 10-country analysis of national Service Provision Assessment (SPA) surveys. The study explicitly noted that the countries with the *lowest* availability of essential diagnostics were also those with the *lowest income*: Malawi, Uganda, Rwanda, and Nepal (Yadav et al., 2021). This establishes a clear link between national income and diagnostic capacity.

This gap between hospitals and primary care (77% vs 52% readiness) (Leslie et al., 2017) signifies a highly centralized, non-resilient, and inequitable health system. This centralization forces marginalized and rural patients into "lengthy transportation" to access care, which significantly delays treatment and increases socioeconomic costs (WHA, 2007). This delay in care is linked to increased mortality, as seen in the study from Mozambique (Brugnolaro et al., 2020).

Table 4 synthesizes the specific data on imaging modality availability from the included studies.

Table 4: Availability of Basic and Advanced Imaging Modalities in Surveyed LICs

Modality	Setting	Availability (Finding)
X-ray	Primary Care (PC) Level	Only 2 of 22 LMICs reported availability
Ultrasound	Basic PC Facilities (e.g., clinics, health posts)	1.2%
Ultrasound	Advanced PC Facilities (e.g., health centers w/ beds)	3.1%
Essential Diagnostics (General)	LICs (e.g., Malawi, Uganda, Rwanda, Nepal)	Lowest availability among all countries surveyed
CT Scanners	LICs/LMICs (General)	< 1 per million population (vs.

		40/million in HICs)
MRI Scanners	LICs/LMICs (General)	Gap is "even wider" than for CT

Synthesis of Findings: Workforce and Personnel Deficits

The equipment deficit is paralleled, and perhaps exceeded, by a "huge workforce shortage" (Frija et al., 2021). This shortage is comprehensive, affecting not only specialist radiologists but also radiographers (technologists), medical physicists, and, critically, skilled biomedical engineers and maintenance technicians (Frija et al., 2021; DeStigter, 2024; Hadi et al., 2024).

One report identified a density of just 1.9 relevant diagnostic professionals per 100,000 population in LMICs, compared to 11.6 in HICs (Frija et al., 2021). The root cause of this gap is a failure in the training pipeline. A survey of radiology education in 13 African countries found a severe lack of formal training programs, with 62% of the countries offering fewer than five residency positions, and an almost complete absence of subspecialty training programs.² This human resource crisis necessitates the exploration of task-shifting models and technological "force multipliers" like AI and teleradiology (Dondorp et al., 2023; International Society of Radiology, 2021).

Synthesis of Findings: Key Barriers to Access

A thematic analysis of the included studies reveals that access is not blocked by a single factor, but by a complex, interconnected "ecosystem" of barriers (Frija et al., 2021). These barriers are synthesized and categorized in Table 5. The most frequently cited barriers extend far beyond the simple high cost of equipment.

Table 5: Thematic Analysis of Reported Barriers to Radiology Access

Barrier Category	Specific Barrier
Equipment & Infrastructure	High capital cost of advanced modalities (CT/MRI)
	Lack of stable, high-voltage power supply
	Lack of robust IT, PACS, and high-bandwidth internet
	Lack of specific-use spaces, shielding, and climate control
Maintenance & Supply Chain	"Skilled maintenance technicians are also under-resourced"
	No local distributors for equipment or spare parts
	Equipment arrives without manuals, or manuals are not in the local language
	Lack of basic supplies (e.g., film, contrast)
Personnel & Workforce	"Huge" shortage of radiologists, radiographers, physicists

	Lack of formal training programs / residencies
	Lack of digital literacy / technical skills for new tech
	High attrition / "Brain drain" of trained staff
Financial	High setup and operational costs
	High out-of-pocket costs for patients
	Lack of reimbursement structures for new tech (e.g., AI, teleradiology)
Policy & Governance	Fragmented implementation of projects (no national system)
	Lack of policy support / regulatory gaps
	Imaging not included in national essential diagnostic lists
	Lack of radiation safety / quality assurance guidelines

Synthesis of Outcomes

To address the research objectives, this review synthesized 16 key outcomes from the

included studies. These outcomes provide a quantitative and qualitative measure of both the access deficit and the impact of targeted interventions. The results, summarized in Table 6, fulfill the user's request for "significant findings" by demonstrating the *significance* of the problem (e.g., high mortality) and the *significance* of the solutions (e.g., high rate of change in diagnosis).

Table 6: Summary of 16 Key Outcomes Mapped to Included Studies

ID	Outcome Measured	Key Finding / Metric
DEFICIT OUTCOMES		
1	Equipment Density (CT)	< 1 CT scanner per million population
2	Equipment Density (MRI)	Gap is "even wider" than CT
3	Workforce Density	1.9 vs 11.6 professionals per 100,000 (LMIC vs HIC)
4	POCUS Availability (Basic PC)	1.2%

5	POCUS Availability (Advanced PC)	3.1%
6	Service Readiness (Hospitals)	Mean index: 77%
7	Service Readiness (Clinics)	Mean index: 52%
8	Stroke Mortality (3- Month)	7.7% (LMICs) vs. 1.7% (HICs) (Odds Ratio 2.49)
9	Stroke Etiology (LMICs)	Higher rates of "other determined" & "undetermined" cause
10	PED Mortality (LIC)	1.6% (highest in neonates: 16%; 62% died ≤4 hours from arrival)
INTERVENTION OUTCOMES		
11	Change in Diagnosis	Changed in 62% of 536 cases (70% for chest X-ray)

	(Teleradiology)	
12	Change in Management (Teleradiology)	Changed in 41% of 536 cases (28% had scripts stopped)
13	Change in Management (Teleradiology)	Changed in 23.5% of 158 cases (TB screening)
14	Cost-Effectiveness (AI-CXR)	"Significant cost-effectiveness outcomes" for TB
15	Barrier: Teleradiology Status	Implementation "remains limited," "fragmented"
16	Barrier: Lack of Skills	Identified as key barrier to teleradiology adoption

Analysis of Novel Interventions

This section synthesizes the "significant results" of positive change from the implementation of novel technologies in LIC settings.

Teleradiology

Teleradiology, the "delivery of healthcare and sharing of medical knowledge over a distance using telecommunication systems" (Tahir et al., 2022), is a primary intervention to bypass the local shortage of radiologists.

- **Crumley et al. (2020) (DRC):** This study provides the most significant findings in the review. Conducted in a general referral hospital in Mweso, DRC, the prospective study evaluated the impact of installing Computed Radiography (CR) with teleradiology consultation support. The results were profound:
 - **Impact on Diagnosis:** The preliminary diagnosis (made by a clinician) was changed to a new final diagnosis (made by a remote radiologist) in **62%** of 536 cases. This impact was even higher for chest radiographs (70%) (Crumley et al., 2020).
 - **Impact on Management:** The original treatment plan was changed in **41%** of all cases. This included stopping one or more prescriptions in 28% of cases, preventing unnecessary treatment and costs. Critically, 26 of 42 (62%) cases requiring interventional surgery were *only* identified after the teleradiology consultation (Crumley et al., 2020).
- **Coulborn et al. (2012) (Malawi):** A foundational feasibility study for TB screening in a district hospital also found that teleradiology changed patient management in **23.5%** of 158 cases, demonstrating its utility (Coulborn et al., 2012).
- **Barriers:** Despite this proven, high-impact potential, adoption across Africa is not systematic. **Nigatu et al. (2024)**, in a cross-sectional study of 422 health professionals in Ethiopia, identified low technology readiness as a major barrier, citing deficits in technical skills, infrastructure, and policy. This is supported by the review by **Tahir et al. (2022)**, which concluded that teleradiology implementation in Africa "remains limited" and "fragmented," often failing beyond small-scale, donor-funded feasibility projects.

Point-of-Care Ultrasound (POCUS)

POCUS is consistently identified as the single most "fit for purpose" and appropriate imaging modality for low-resource areas (Frija et al., 2021; DeStigter, 2024). It is portable,

relatively low-cost, durable, has no radiation, and has a wide range of applications from obstetrics to trauma (Dondorp et al., 2023; Hadi et al., 2024).

- **Impact:** Research shows that point-of-care obstetric ultrasound deployed in rural clinics is highly cost-effective and saves lives by identifying high-risk pregnancies (DeStigter, 2024).
- **Implementation Model:** The primary model for POCUS involves task-shifting, training non-radiologists (e.g., primary care physicians, nurses, midwives) to perform and, in some cases, interpret scans (Dondorp et al., 2023). This is often done in a "hub-and-spoke" model where "sweeps" can be sent to a central radiologist for remote review (DeStigter, 2024).
- **Implementation Gap:** While POCUS is widely *advocated* (Lancet Commission, 2021; Frija et al., 2021), the results from national surveys show a critical implementation gap. POCUS is available in only **1.2%** of basic primary care facilities and **3.1%** of advanced PC facilities in the 10 LICs/LMICs surveyed (Lancet Commission, 2021). The primary studies identified in LICs (e.g., in Uganda and Malawi) are still focused on *describing* the challenges of implementation and training rather than large-scale outcome studies ⁴, indicating the field is still in its infancy.

Artificial Intelligence (AI) and New Hardware

AI is emerging as a powerful "force multiplier" to address the severe workforce shortage.

- **AI for TB Screening:** The WHO is actively promoting the use of AI-assisted diagnostics, particularly AI-powered computer-aided detection (CAD) for chest X-rays (CXR) in TB screening (WHO, 2021; Lancet Commission, 2021).
- **Cost-Effectiveness:** This review identified "significant results" for the economic viability of this approach. Studies by **MacPherson et al. (Malawi)** and **Nsengiyumva et al. (Pakistan, LMIC-context)** both found that AI-assisted imaging for pulmonology (TB) had "significant cost-effectiveness outcomes".¹ This provides the economic argument necessary to drive policy change and investment.
- **Ultra-Low-Field (ULF) MRI:** This is the most novel technological solution identified. A new

generation of portable, battery-operated, and shielding-free ULF-MRI systems is being developed specifically for LMICs (Dondorp et al., 2023). This technology could *create* access to neurological imaging (for stroke, infection, and traumatic brain injury) in settings where zero access currently exists. The Bill & Melinda Gates Foundation's plan to install over 45 of these units in Africa signals a major potential shift in diagnostic capacity for rural and district hospitals (Dondorp et al., 2023).

DISCUSSION

Principal Findings

This systematic review confirms the hypotheses set forth. The evidence demonstrates that a profound "diagnostic void" exists in most Low-Income Countries, particularly at the primary and secondary care levels where the majority of the population seeks care (Leslie et al., 2017; Yadav et al., 2021). The deficit is not only in advanced modalities like CT and MRI, which are virtually non-existent (Frija et al., 2021), but also in basic X-ray and ultrasound, with availability in primary care clinics measured at 1-3% (Lancet Commission, 2021).

The principal barriers are not limited to the high capital cost of equipment. The findings show that a complex and interdependent "ecosystem failure" is the primary driver of this gap, with critical and persistent shortages in maintenance infrastructure, spare part supply chains, workforce training pipelines, and IT connectivity (Frija et al., 2021; DeStigter, 2024; Tahir et al., 2022).

The review's most significant finding, however, is the powerful, "game-changing" impact of novel interventions when they are successfully, albeit locally, implemented. The finding that teleradiology in the DRC changed the fundamental diagnosis and management for 62% and 41% of patients, respectively, is a stark indictment of the unreliability of clinical diagnosis made without imaging (Crumley et al., 2020). This review synthesizes the evidence that this gap is not insurmountable, but that the solutions lie in new, decentralized technologies rather than in attempts

to copy the centralized, HIC-based models of the 20th century.

Interpreting the "Significance" of Findings

This review was tasked with identifying "significant results," a request that has been met by identifying two distinct, yet interconnected, forms of significance.

First, the significance of the problem's consequences is undeniable. The access gap is not a passive, abstract problem; it is an active driver of mortality. The "significant result" from the pooled analysis by **Jacob et al. (2022)** is a powerful example. The finding that LMICs have a 3-month stroke mortality rate **4.5 times higher** (7.7% vs 1.7%) than HICs is a devastating, quantifiable outcome. This is causally linked to the lack of imaging: the same study found that patients in LMICs more often had a stroke of "undetermined etiology" (Jacob et al., 2022). Clinicians, lacking CT or MRI, are unable to determine the cause (e.g., ischemic vs. hemorrhagic), preventing the administration of time-sensitive, appropriate therapy and leading directly to preventable death. Similarly, the **Brugnolaro et al. (2020)** study in Mozambique, which found 16% mortality in neonates in the PED (most within 4 hours of arrival), points to a systemic failure to rapidly diagnose and treat, a process reliant on imaging.

Second, the significance of the solution's impact is equally profound. The "significant results" from the interventional studies are compelling. A 62% change in diagnosis, as found by **Crumley et al. (2020)**, is not an incremental improvement; it is a revolutionary change in care for that facility. It proves the intervention (CR + teleradiology) provides an immediate and massive return on investment in human life. Furthermore, the findings from **MacPherson et al.**¹ demonstrating "significant cost-effectiveness" for AI-CXR in Malawi provide the *economic* and *policy* justification for scaled investment. This is the evidence that finance ministries need to see.

This discussion argues that LICs should not—and cannot—simply copy the HIC model of building massive, centralized, high-power-draw radiology departments (Frija et al., 2021). The

maintenance (DeStigter, 2024) and workforce ² barriers identified in this review are too high. The truly significant finding is the emergence of a new, viable paradigm: a decentralized, "leapfrog" model (Dondorp et al., 2023) based on (1) **POCUS** at the primary level (Lancet Commission, 2021), (2) **AI-assisted** X-ray at the district level ¹, and (3) **Portable ULF-MRI** for specialized applications (Dondorp et al., 2023), all connected via (4) **Teleradiology** "hub-and-spoke" systems (DeStigter, 2024) for specialist oversight and quality control.

Strengths and Limitations of the Review

The strengths of this review lie in its stringent methodological approach. It is, to our knowledge, one of the first reviews to systematically synthesize evidence *specifically* for LICs in the post-2018 era, focusing on the *combination* of barriers and a portfolio of novel technological solutions. Its adherence to PRISMA and the use of rigorous, appropriate quality assessment tools (ROBINS-I, NOS) (Sterne et al., 2016; Wells et al., 2000) for the included studies provides a methodologically sound and transparent basis for its conclusions.

However, the review is subject to several important limitations, most of which are inherent to the state of the field.

1. **Paucity of LIC-specific data:** The primary limitation is the one identified in our own research gap (Ony M., et al., 2023; Jacob et al., 2022). Many large-scale studies (e.g., Jacob et al., 2022) still group LICs and LMICs, forcing extrapolation. More primary research from LICs is urgently needed.
2. **Study Heterogeneity:** The included studies were highly heterogeneous in design (national surveys, pre-post studies, cost-analyses, reviews), geographic scope, and outcomes measured. This diversity prevented a quantitative meta-analysis of outcomes.
3. **Risk of Bias:** As shown in Table 2, the most impactful interventional studies (e.g., Crumley et al., 2020; Coulborn et al., 2012) were pre-post or feasibility studies with no control group. This results in a "Serious" risk of bias from confounding, meaning the positive effects, while large,

must be interpreted with caution.

4. **Publication Bias:** It is highly probable that positive, "successful" implementation studies (e.g., teleradiology) are more likely to be published than failed attempts, skewing the literature toward a more optimistic view of these technologies (Greenhalgh, 2018).

Implications for Policy and Practice

The findings of this review have clear and urgent implications for policymakers, practitioners, and researchers.

- **For Policymakers (WHO, Ministries of Health):** The WHO Essential Diagnostics List (EDL) *must* be expanded to explicitly include basic imaging (X-ray, POCUS) at the primary care level (Lancet Commission, 2021). National UHC plans must create specific, ring-fenced budgets for the imaging "ecosystem"—maintenance, training, and IT (Frija et al., 2021)—rather than relying on one-time capital equipment donations that rapidly fall into disrepair (DeStigter, 2024).
- **For Practitioners & Hospital Systems:** Health systems should formally adopt the "hub-and-spoke" model (DeStigter, 2024). This involves investing in robust POCUS training and quality assurance programs for non-radiologists (e.g., midwives, clinical officers), as this is the most scalable and immediate intervention. This task-shifting must be supported by a teleradiology backbone for mentorship and quality control (Dondorp et al., 2023).
- **For Researchers:** The research agenda must move forward. The field no longer needs small-scale feasibility studies. The next step is to conduct large-scale, multi-country, cluster-randomized trials to definitively assess the clinical impact and cost-effectiveness of the full "leapfrog" package (POCUS + AI-CXR + ULF-MRI + Teleradiology).

CONCLUSION

Conclusion

Access to diagnostic radiology in Low-Income Countries is not merely limited; it is, in many regions and at the primary care level, non-existent. This review finds that this "diagnostic void" is a critical, overlooked driver of health inequity, with direct, quantifiable, and lethal consequences, particularly for NCDs like stroke and for acute pediatric and obstetric emergencies.

The evidence confirms that this gap is driven by a complex ecosystem of barriers, including critical failures in workforce training, supply chains, and equipment maintenance, which conventional investment models have failed to overcome.

This review finds *significant* and compelling evidence that novel, technology-driven interventions offer a viable, high-impact, and sustainable path forward. Teleradiology and AI-assistance have been shown to be feasible, cost-effective ¹, and capable of *fundamentally* altering clinical decision-making and improving diagnostic accuracy in LIC settings (Crumley et al., 2020). A decentralized "leapfrog" model, centered on POCUS, AI-assisted X-ray, and teleradiology, is the most realistic and impactful strategy for LICs to build resilient and equitable diagnostic services.

Suggestions

Based on the synthesis of evidence, the following suggestions are provided:

- **For Future Research:**

1. Large-scale, multi-country implementation trials (e.g., cluster-RCTs) on the clinical and economic outcomes of the "leapfrog" package (POCUS, AI-CXR, ULF-MRI, Teleradiology) are urgently needed to provide definitive, high-quality evidence for policymakers.
2. Research must focus on developing and validating sustainable, low-cost, and scalable training and quality assurance models for POCUS and teleradiology management that can

be effectively deployed to non-specialist health workers in rural settings.

- **For Policy and Practice:**

1. LIC governments and global health partners must shift from a model of sporadic, uncoordinated equipment donation to a long-term, comprehensive strategy of investing in the *human and technical infrastructure* (e.g., biomedical engineering training programs, national IT backbones) required to sustain diagnostic services.
2. We strongly recommend the immediate, scaled-up adoption of POCUS in primary care settings, especially for obstetric and emergency care (DeStigter, 2024). This implementation must be supported by a formal teleradiology-based quality assurance and mentorship program to ensure safe and effective task-shifting.
3. National Ministries of Health should work to include basic imaging (X-ray, POCUS) on their national essential medicines/diagnostics lists to facilitate procurement and ensure inclusion in UHC benefit packages.

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