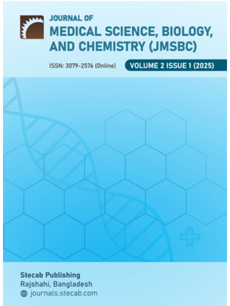

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*Review Article*

# Digital Transformation in Radiography Practice in Nigeria: A Comprehensive Review

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## About Article

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## ABSTRACT

Digital radiography has steadily transformed medical imaging practice in Nigeria over the past two decades, shifting from analog film-based workflows to computerized systems. This narrative review synthesizes literature (2000–2025) on Nigeria's adoption of digital imaging modalities, the evolving policy environment, operational and economic challenges, workforce training, impacts on workflow and patient outcomes, emerging innovations, and considerations of equity, ethics, and sustainability. Key findings include a slow but accelerating adoption trajectory from the early 2000s through the 2010s, with policy and regulatory frameworks only beginning to catch up. Power supply issues (the infamous NEPA outages) and high costs impede full integration, even as digital systems improve efficiency and image quality. Workforce competencies are improving through training, yet gaps remain in specialized skills. Innovations such as teleradiology, artificial intelligence (AI) for tuberculosis screening, and virtual reality (VR) training are emerging in Nigeria, though equitable access and data governance pose ongoing challenges. In sum, Nigeria's radiography is undergoing a cautious digital revolution with tangible benefits for workflow and patient care, tempered by resource and infrastructure constraints.

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## 1. INTRODUCTION

Radiographic practice in Nigeria is experiencing a paradigm shift from the analog era of darkrooms and chemical film processing to the digital age of computers and networks. For decades following the introduction of X-rays, Nigerian hospitals relied on film-based imaging, which came with its own set of limitations, including lost films, repeated exposures, and the logistical challenge of storing heavy archives of X-ray folders. Until the early 2000s, modalities like Computed Radiography (CR) or Direct Digital Radiography (DR) were mostly confined to theory in Nigeria's radiography schools. A 2011 survey in Edo State found that no X-ray facility had a digital radiography unit or computerized record system at that time (Eze *et al.*, 2011). These snapshots of the past underscore how far the journey has come: today, digital imaging is increasingly visible across teaching hospitals and diagnostic centers in the country. The impetus for digital transformation in radiography is clear. With a population exceeding 200 million and a severe shortage of radiologists (fewer than 300 for the whole country as of the mid-2010s) (Ekpo *et al.*, 2015), Nigeria faces immense pressure to improve diagnostic services. Digital tools promise quicker image acquisition, easier distribution of images for consultation, and potentially more accurate diagnoses. We can envisage a conceptual framework where inputs (infrastructure, funding, policy support, skilled personnel) feed into digital processes/tools (e.g., CR/DR machines, Picture Archiving and Communication Systems (PACS), teleradiology platforms), which in turn influence throughputs (workflow efficiency, image quality, access to specialist interpretation) and ultimately yield health outcomes (faster diagnosis and treatment, reduced patient waiting times, improved patient safety and satisfaction). In simple terms, digital radiography tools can meaningfully enhance clinical outcomes by speeding up and improving the imaging process, provided that the right building blocks, stable electricity, internet connectivity, trained staff, and supportive policies are in place.

However, the path is not without obstacles. Nigeria's healthcare infrastructure is heterogeneous, with cutting-edge digital suites in some urban tertiary centers and aging film-based units in many rural clinics. Policy and regulation often lag behind technological change, raising questions about standardization, data security, and professional scope of practice. Economically, the high cost of digital equipment and maintenance strains limited budgets, leading to creative workarounds (or sometimes inertia). Culturally, the radiography workforce must adapt to new roles and continuous learning; for instance, radiographers now interface with software and even perform preliminary image interpretations, a role traditionally left to radiologists (Ekpo *et al.*, 2015).

This comprehensive review explores how these multidimensional factors are shaping radiography practice in Nigeria's digital transformation journey. We integrate evidence from peer-reviewed journals (e.g., PubMed-indexed studies, African Journals Online) and reputable grey literature (policy documents, project reports) focusing on Nigeria from 2000 to 2025, with comparative insights from other low- and middle-income countries (LMICs) where relevant. The review is structured to examine the adoption trajectory of digital imaging, the regulatory and policy environment, operational and economic realities on the ground, workforce competency and training issues, the impact on workflow, image quality and patient outcomes, emerging technologies driving innovation, and cross-cutting themes of equity, ethics, and sustainability.

## 2. LITERATURE REVIEW

This focused synthesis compares the most-cited Nigerian studies across three recurring themes and pinpoints the outstanding evidence gaps our review addresses.

### 2.1. Workforce Skills

E research centred on knowledge deficits among frontline staff. Ekpo *et al.* (2015) showed radiographers could interpret chest radiographs with 77% sensitivity and 80% specificity, but performance correlated strongly with years of experience, signalling uneven diagnostic competence. More recently, Esien-Umo *et al.* (2023) found that only 24.7% of radiographers understood the Exposure-Index concept and just 8.3% could apply it to optimise dose. Collectively, the data reveal patchy uptake of digital-specific quality-control skills, yet no national survey has mapped competencies across all six geo-political zones or linked them to patient outcomes.

### 2.2. Technological Infrastructure

Eze *et al.* (2011) documented a complete absence of CR/DR units in 18 Edo-State facilities and attributed the lag chiefly to acquisition costs. A decade later, Yunusa *et al.* (2021) reported that 87% of staff at a tertiary centre in Kano had access to PACS, but downtime from power instability and limited vendor support undermined perceived benefits. Pilot deployments of ultra-portable DR-CAD units for TB screening (2021-2023) screened 130 000 people across eight states and confirmed technical feasibility off-grid, yet rigorous cost–effectiveness studies remain pending. No longitudinal dataset currently tracks equipment age, uptime, or replacement cycles nationally.

### 2.3. Policy Landscape

Nigeria's Health ICT Strategic Framework (2015-2020) and the NDPR (2019) establish broad e-health and data-protection mandates, but neither defines radiology-specific quality or security standards. Regulatory analysis shows that the NNRA still applies technology-neutral QC rules, with no separate digital detector guidelines. Curriculum policy has moved faster: the National Universities Commission's 2021 CCMAS explicitly requires digital-imaging competencies, yet implementation fidelity varies and has not been empirically evaluated.

### 2.4. Research Gap

Existing studies are single-centre, cross-sectional, or technology-pilot reports that illuminate isolated facets—skills, hardware, or regulation—but seldom integrate them. There is no comprehensive, Nigeria-wide synthesis that (a) threads workforce capability, infrastructural readiness, and policy maturity into a single narrative, (b) benchmarks progress against other LMICs, and (c) identifies scalable levers for sustained digital growth. The present review addresses that gap by thematically collating evidence from 2000-2025 and translating it into actionable policy and investment priorities.

## 3. METHODOLOGY

We conducted a narrative literature review without formal meta-analysis, aiming for a broad synthesis of current knowledge on digital transformation in Nigerian radiography. Searches were performed in PubMed, Google Scholar, African Journals Online (AJOL), IEEE Xplore, and relevant grey literature sources (e.g., government and NGO reports) for the period 2000 through early 2025. Key search terms included combinations of "digital radiography Nigeria," "PACS Nigeria," "teleradiology Africa," "radiography training Nigeria," and "medical imaging technology Nigeria," among others. We included studies focusing on Nigeria and selectively incorporated comparative insights from other LMICs to contextualize Nigeria's experience. Both quantitative studies (e.g., surveys, observational studies) and qualitative or commentary papers were reviewed.

Each piece of literature was rated as low, moderate, or high quality based on study design, sample size, methodological rigor, and relevance. For instance, multi-center surveys published in reputable journals were deemed moderate to high quality, whereas single-site case studies or opinion pieces were considered low quality. We prioritized evidence from moderate- and high-quality sources to support key points, while still noting findings from lower-quality or anecdotal reports when they provided useful details about real-world challenges (these are clearly indicated as such in the discussion). Overall, the evidence base on this topic is dominated by cross-sectional surveys and descriptive studies (moderate quality) with a paucity of interventional or longitudinal research (few high-quality studies). These factors influenced our approach to synthesize findings thematically rather than quantitatively.

Data from the sources were charted into the thematic categories reflected in our Results & Discussion sections. Given the narrative scope, we did not strictly follow PRISMA guidelines; however, we ensured transparency in sourcing and attempted to capture the breadth of issues.

## 4. RESULTS AND DISCUSSION

### 4.1. Adoption Trajectory of Digital Imaging

The journey of digital imaging adoption in Nigeria's radiography practice has been gradual and uneven, marked by early lags and recent leaps. In the early 2000s, radiography training and practice were still overwhelmingly analog. Anecdotal accounts illustrate that as late as 2003, radiography students could complete their five-year program without ever handling a digital imaging unit; CR and DR existed only in textbooks. This reality was mirrored in practice: a seminal 2011 survey by Eze *et al.* observed that none of the 18 functional X-ray centers in Edo State had transitioned to digital radiography at that time (Eze *et al.*, 2011). Clinics were using film-screen systems exclusively, meaning lost or damaged X-ray films necessitated repeat exposures and additional radiation to patients (Eze *et al.*, 2011). Such findings from a decade ago paint a picture of a nation only beginning to awaken to digital possibilities.

The mid-2010s witnessed a gradual shift in the situation. Spurred by global trends and the availability of more affordable digital solutions, some forward-looking institutions invested in digital radiography equipment. Notably, the Delta State University Teaching Hospital (DELSUTH) Oghara was established as a filmless radiology department from its inception in 2010–2011, becoming the first teaching hospital in Nigeria to implement a full PACS/RIS and digital workflow (DELSUTH Radiology, n.d.). This early adopter case demonstrated that going straight to digital was feasible in Nigeria, at least in a new tertiary hospital with government support. Around the same period, a few federal teaching hospitals and high-end private diagnostic centers, such as the University of Abuja Teaching Hospital in Gwagwalada, implemented computed radiography (CR) systems, often via government procurement or donor funding (Nemi *et al.*, 2021). By 2020, digital radiography units (particularly CR cassettes and DR flat panels) had proliferated in many urban hospitals (Idowu & Okedere, 2020). A 2021 cross-sectional survey of radiography staff in National Orthopaedic Hospital Dala-Kano found that 85% reported having access to some form of digital imaging (CR or DR) at their facility (Saidu *et al.*, 2021). While this statistic suggests near-ubiquitous adoption, it likely reflects a sample bias toward larger hospitals in the survey; nonetheless, it reflects that digital imaging is no longer a rarity in the Nigerian radiology landscape.

The adoption trajectory also encompasses the advent of teleradiology, transmitting images for remote interpretation, which became practical once images were digital. By the late 2000s, a few pilot teleradiology projects connected radiology departments, such as the Upstream Nigeria Telemedicine Pilot Program launched in March 2010, which connected radiology departments within Nigeria or with consultants overseas, albeit on a limited scale (Dodoo *et al.*, 2022). Early technical challenges (slow internet, poor image quality) hindered expansion. But recent advances have made teleradiology increasingly viable. A 2022 review notes that mobile teleradiology using smartphones and cellular networks is now feasible in sub-Saharan Africa, including Nigeria (GSMA, 2022; Tahir *et al.*, 2022). Indeed, informal teleradiology already occurs: it's not uncommon for a radiographer in a district hospital to WhatsApp a digital X-ray image to a radiologist in another city for a quick second opinion (Erik L. Ridley, 2015). Such stop-gap solutions highlight the creative adoption of digital tools to bridge human resource gaps.

Nigeria's adoption curve remains lengthy despite its progress. Many general hospitals and private clinics, especially in semi-urban and rural areas, continue to use aging analog X-ray machines due to cost constraints. The presence of digital radiography is heavily skewed toward higher levels of care. This gap between early adopters and laggards means that a patient's experience can differ widely: one patient might get a digital X-ray and a CD copy of images in a teaching hospital, while another, at a remote clinic, still holds an X-ray film against the sunlight to view it.

### 4.2. Regulatory & Policy Environment

The regulatory and policy landscape in Nigeria has only recently begun to catch up with the digital transformation in radiography. In the early phases of digital adoption, there was a notable policy vacuum; hospitals and radiology units forged ahead with purchasing digital equipment, often in the absence of specific national guidelines or standards. Nigeria's Federal Ministry of Health acknowledged the importance of health ICT in its National Health ICT Strategic Framework 2015–2020, which provided a broad roadmap for e-health integration, including telemedicine, into the healthcare system (Ministry of Health, Nigeria, 2016). However, this framework was largely aspirational, lacking detailed provisions or enforcement mechanisms for radiology-specific applications. As a result, implementation of digital radiography has been driven more by institutional initiatives than by central mandate.

Professional regulatory bodies have started to integrate digital competencies into their oversight. The Radiographers Registration Board of Nigeria (RRBN), responsible for the training and licensing of radiographers, revised curriculum requirements in the 2010s to ensure new graduates receive training on digital imaging modalities and computer applications in radiography (Healths.ng, 2023). The National Universities Commission (NUC) introduced a new Core Curriculum Minimum Academic Standards (CCMAS) in 2021, which explicitly encourages inclusion of modern technologies (like digital imaging and even VR tools) in radiography education. These steps indicate recognition at the policy level that digital skills are essential for the future workforce. Additionally, the Association of Radiographers of Nigeria (ARN) has been organizing continuing professional development workshops focusing on topics such as PACS administration, teleradiology, and radiation dose management in digital systems, thereby indirectly influencing practice standards (Vincent Ukpong *et al.*, 2024).

When it comes to telemedicine and teleradiology regulation, Nigeria is still in a nascent stage. As of May 2025, there is no specific legislation dedicated to telemedicine or teleradiology in the country (Global Law Experts, 2024). Existing laws governing medical practice and patient privacy apply in general, but they do not address nuances like cross-jurisdictional tele-reporting or electronic transmission of patient data. The absence of clear telemedicine laws means that institutions venturing into teleradiology operate in a gray zone: for example, can a radiologist based in Lagos officially report X-rays for a hospital in Enugu via teleradiology, and will such reports be recognized medicolegally? In practice it happens, but formal recognition is pending until regulatory frameworks catch up (Ngozi Emeka, 2023). The Nigeria Data Protection Regulation (NDPR) (enacted by NITDA in 2019) provides some guidance on handling personal data, which would include digital medical images, mandating data security and patient consent for electronic data handling, an important legal backdrop for any PACS or cloud storage of radiographs (Wole Alao, 2021).

Radiation protection regulations, enforced by the Nigerian Nuclear Regulatory Authority (NNRA), focus on equipment standards and dose safety but are largely technology-neutral. They require any X-ray facility (analog or digital) to be licensed and periodically inspected. Digital equipment must meet international standards (such as having dose display and failsafes), but there are not yet Nigeria-specific standards for quality control of digital radiography units beyond what applies to analog machines (NNRA, n.d.). This regulatory lag can sometimes lead to the suboptimal use of digital tools, such as the absence of enforced quality assurance programs for digital systems or standardized calibration protocols.

Policy-makers are gradually recognizing these gaps. As digital imaging becomes prevalent, we anticipate more explicit guidelines to emerge. Draft policies on telehealth were circulated in Nigeria's Federal Ministry of Health in recent years, and the Radiology Guild (a body of radiologists) has advocated for standards on teleradiology reporting and archiving. Still, much of the current governance falls back on institutional policies—for instance, teaching hospitals may have their own rules about who can access PACS, how long images are stored, or whether radiographers can make initial reports on digital images.

In summary, the policy environment is evolving from a previously laissez-faire stance to one of cautious structuring. The need for clear regulations is evident to ensure patient data privacy, standardize image quality, and delineate professional responsibilities in the digital era. Collaborative efforts between government, professional bodies, and healthcare institutions are needed to formulate guidelines that keep pace with technological advances.

### 4.3. Operational & Economic Realities

Implementing and sustaining digital radiography in Nigeria comes with a suite of operational and economic challenges that can significantly influence day-to-day practice. Chief among these is the issue of infrastructure, especially electric power supply. Nigeria's electricity grid is infamously unreliable; the colloquial phrase "NEPA has taken light" (a nod to the former National Electric Power Authority) still rings true in hospitals across the country (Ubalaeze *et al.*, 2024). Digital radiography equipment, from DR panels to PACS servers, requires stable power and often climate-controlled environments. Frequent power outages (sometimes several times a day) mean hospitals must rely on backup generators to keep imaging services running. This "epileptic power supply" was highlighted as a major obstacle by radiology staff in a 2021 PACS implementation study in Kano (Saidu *et al.*, 2021). Every power fluctuation risks abrupt shutdowns of sensitive equipment or data corruption on servers. Many facilities have had to invest in uninterruptible power supplies (UPS) and allocate part of their budget for diesel fuel for generators, which can be prohibitively expensive. Smaller clinics that cannot afford robust backup power simply schedule X-ray services only during times they can run a generator, or, worst-case, revert to analog methods if their digital system cannot tolerate the inconsistencies. Thus, the dream of digital efficiency can be hampered by a very analog problem: electricity.

Another operational hurdle is equipment maintenance and technical support. Digital X-ray machines and PACS software are sophisticated technologies usually imported from Europe, North America, or East Asia (Stop TB Partnership, 2023) . When (not if) they break down, getting them serviced is a logistical challenge. Replacement parts might need to be shipped in (Eneogu *et al.*, 2024). Local biomedical engineers often lack specialized training for these systems, meaning dependence on the vendor's technicians. In a 2023–2024 TB screening project in Nigeria using ultra-portable digital X-ray units equipped with CAD software, field teams reported significant delays when units malfunctioned, with some devices remaining out of service for over six weeks while awaiting parts and vendor support (S *et al*., 2025; Stop TB Partnership, 2023).

In many public hospitals, however, maintenance contracts are either absent or expired, and budgetary constraints lead to delays in repairs (Odume *et al*., 2022). A digital X-ray unit might sit idle for months waiting for a new digital detector or a software fix, a scenario far less common with simpler analog machines that local technicians can often patch up. This circumstance introduces a paradox: acquiring digital equipment is only the first step; maintaining it is the real marathon.

Cost factors weigh heavily on decision makers. The initial capital outlay for digital radiography is substantial. For example, a new DR X-ray machine can cost several times the price of an analog unit (Ozcete *et al*., 2016). In addition, setting up a PACS network, including servers, workstations, and secure storage, often adds hundreds of thousands of dollars in hardware and IT infrastructure costs; for example, the PACS project at University College Hospital Ibadan required an upfront investment of over USD 200,000 for equipment and installation alone (Elahi *et al*., 2020). While digital systems eliminate the recurring cost of film and chemicals (and the darkroom staff), these savings only materialize over time and with sufficient patient throughput. In a low-volume center, film costs might have been lower than the amortized cost of a digital system. This economic calculus has made some hospital administrators hesitant. A 2024 scoping review of digital-health technology adoption in Nigeria likewise identified initial purchase expenses and ongoing maintenance costs of digital imaging platforms as primary barriers across multiple health disciplines, radiography included (Oke & Sibomana, 2025). Hospitals operating on tight budgets or relying on internally generated revenue face tough choices: should they purchase a digital unit or hire an extra radiologist? Replace a failing CR reader or stock up on other basic supplies? Consequently, many government hospitals waited for federal programs or grants to subsidize digital upgrades. Donor-funded projects (e.g., those by international health NGOs) have occasionally filled the gap by donating CR readers or PACS systems, but this raises questions of sustainability once the donors withdraw.

Workflow disruptions during the transition period also pose operational challenges. Switching from film to digital requires re-engineering processes—processes where radiographers must learn new acquisition techniques and software interfaces; radiologists and referring clinicians need training on viewing soft-copy images (some doctors initially insisted on printing films even from digital systems, uncomfortable with on-screen reading). Although there can be resistance to change, a recent study on VR adoption in radiography education in southeast Nigeria interestingly found that most staff and students did not view resistance to new technology as a significant issue. This suggests the culture is becoming more tech-accepting, especially among younger professionals. Still, older radiographers who spent decades with film may feel nostalgic or hesitant, requiring supportive change management. During the early phase of PACS implementation, it's common to run dual systems (film and digital), which can be chaotic. There are anecdotes of images accidentally not saved to PACS, or network downtime forcing a reversion to manual methods. All these teething problems require strong institutional support and patience.

From an economic standpoint, arguments in favor of digital often cite long-term cost-effectiveness and efficiency. Indeed, studies outside Nigeria have shown that while initial costs are high, the cost per examination can drop with digital workflows due to higher throughput and elimination of consumables. Moreover, intangible benefits like faster diagnosis and reduced repeats (because images aren't lost or of poor quality) enhance the value proposition. Some Nigerian hospitals report improved revenue when going digital, as they can handle more patients per day and even attract referrals (patients increasingly prefer centers that offer digital services, equating them with higher quality). Private radiology centers in metropolitan areas leverage their digital capabilities as a marketing edge, showcasing features like "get your X-ray on CD or via email" to tech-savvy clientele.

In summary, the operational and financial realities of digital radiography in Nigeria require a careful balance. The advantages in efficiency and image quality are clear, but realizing them requires overcoming infrastructural weaknesses and ensuring sustained investment. The phrase "cut your coat according to your cloth" comes to mind—each facility must adapt the digital revolution to its means, sometimes through phased adoption (starting with CR before DR or implementing mini-PACS within radiology before hospital-wide).

### 4.4. Workforce Competency & Training

Any technological transformation in healthcare must be accompanied by human capacity development, and Nigeria's experience with digital radiography is no exception. The shift to digital has redefined the skill set required of radiographers, radiologists, and other allied staff. Early on, one of the fears was that older practitioners might be left behind in the digital race. A senior radiographer trained in the 1990s was an expert in darkroom techniques but suddenly needed IT skills to maneuver through menus on a computed radiography workstation. To the credit of the profession, a concerted effort has been made in the past two decades to upskill the workforce. Radiography education in Nigeria now incorporates digital imaging modalities as part of the core curriculum. By the mid-2010s, the updated Benchmark Minimum Academic Standards from the Radiographers Registration Board of Nigeria required universities to give students hands-on experience with computed radiography (CR) or direct digital (DR) systems. Parallel to this, the National Universities Commission's 2021 Core Curriculum Minimum Academic Standards for Allied Health Programs explicitly mandates inclusion of modern imaging technologies—including CR/DR and even virtual-reality teaching aids—in radiography training (Bwanga, 2020). The RRBN's introduction of a compulsory one-year clinical internship in 2001 further ensured that new graduates receive supervised practical exposure to these systems in teaching hospitals.

Still, significant knowledge gaps persist. A 2022 survey of radiographers across southern Nigeria found that although 24.7% of respondents were aware of the Exposure Index (EI), concept in digital radiography, only 8.3% demonstrated good working knowledge of how to apply EI for dose optimization in practice (Esien-Umo *et al.*, 2023). The authors attributed these deficits to the absence of EI training in undergraduate syllabi, the lack of structured continuing education on EI, and limited vendor-provided instruction during equipment commissioning (Esien-Umo *et al.*, 2023). In essence, many radiographers can operate digital systems but are not yet equipped to leverage built-in quality-control tools fully, a classic case of technology outpacing training. This underscores the urgent need for ongoing professional development focused on digital image optimization and radiation-safety practices to prevent "dose creep," where excessive exposures go unnoticed because digital detectors mask overexposure.

Radiologists, for their part, had to adapt from reading large film sheets on light boxes to reading from high-resolution monitors. While top-tier radiologists quickly embraced advanced tools like digital measurement software, there has been variability in uptake. Some older radiologists initially preferred printing digital images onto films for reporting—a practice observed in a few centers in the early transition period, which somewhat negated the benefit of going filmless. But as PACS software interfaces improved and younger, computer-native radiologists entered the field, soft-copy reading has become the norm in places with PACS. Formal training in radiology residency now includes topics such as PACS and imaging informatics, although these subjects are often covered superficially. Opportunities for specialized training (like short courses in imaging informatics or fellowships abroad focusing on digital workflows) are being explored by Nigerian radiologists to build local expertise (Idowu, 2018).

Another important workforce aspect is task-shifting and role extension. With so few radiologists in the country, radiographers often step up to fill gaps in image interpretation, especially in primary care settings. Digital imaging can facilitate this by providing tools like measurement, zoom, and comparison of prior studies. Ekpo *et al.* (2015) assessed 51 Nigerian radiographers using a test set of 50 chest radiographs and found a mean sensitivity of 76.9% and specificity of 79.8%; importantly, performance improved significantly with years since qualification ($p = 0.005$) . The authors concluded that "Nigerian radiographers have the potential to interpret chest X-rays in the clinical setting, and this may significantly improve radiology service delivery in this region" (Ekpo *et al.*, 2015). This finding has fed into a gentle push to formally recognize radiographers' role in preliminary image evaluation or reporting in areas where radiologists are absent. While not yet enshrined in regulation, in practice many radiographers, especially those in remote or night shift duties, are leveraging their competency to give provisional reports. Training programs by NGOs have even targeted radiographers for specialized training in, say, chest X-ray interpretation for tuberculosis screening using digital X-rays effectively broadening the workforce is capable of reading images. This is somewhat controversial in professional circles but undeniably pragmatic for improving patient care in underserved areas.

Continuous Professional Development (CPD) has gained momentum to keep the workforce updated. Both the Radiographers' Board and the Radiologists' College require CPD points for license renewal, prompting attendance at workshops on digital imaging topics (Vincent Ukpong *et al.*, 2024). Equipment vendors also contribute: when a hospital purchases a new digital system, the vendor typically provides on-site training. However, such training can be rushed and focused on basic operation rather than advanced features. Moreover, staff transfers and turnover can erode the knowledge base; a trained person leaves, and the replacement has to learn anew. Recognizing this, some larger radiology departments have started "internal training-of-trainers" models where a few staff receive in-depth training and then serve as resource persons for their colleagues. The radiography community has seen the benefits of peer learning; it's not uncommon to find an enthusiastic young radiographer in each department who becomes the go-to for any PACS question or digital technique advice, essentially acting as a local champion for the technology.

In conclusion, the human capacity element of digital radiography in Nigeria has seen notable improvements yet requires continuous attention. Bridging knowledge gaps (such as awareness of dose indices or advanced PACS use) is vital for maximizing the benefits of digital systems. On the encouraging side, the newer generation of radiographers and radiologists are tech-savvy and eager to innovate, which bodes well for sustained digital practice. As we often say, "The machine is only as good as the person operating" it"—hence, investment in training must go hand-in-hand with investment in equipment.

### 4.5. Workflow, Image Quality & Patient Outcomes

One of the clearest impacts of digital transformation in radiography is on workflow efficiency and service delivery, essentially, how quickly and effectively patients get their imaging results. In a busy radiology department at a Nigerian teaching hospital, the introduction of CR/DR and PACS can dramatically streamline operations. Gone are the bottlenecks of film processing; images appear within seconds on a console. This immediacy reduces patient wait times and enables retakes to be done before the patient even leaves the X-ray room, improving the chances of getting a diagnostic image in one visit.

Studies confirm these practical benefits. In Kano, radiographers overwhelmingly agreed that implementing PACS saved time and improved their workflow; 87% of respondents said PACS saved a lot of their time, and virtually all (99%) felt it improved the quality of their work and patient care. The ability for multiple users to access the same image concurrently means a radiologist can start reviewing a chest X-ray even as the patient is still being transported back to the ward, something impossible in the film era. Furthermore, digital images can be integrated into hospital information systems, enabling clinicians to view radiology results from clinic or theater. This has knock-on effects: surgeons can make intraoperative decisions faster if they can quickly pull up the latest X-ray on a monitor in the operating room, and ER doctors can consult radiologists by simply pointing them to images on the system rather than physically carrying films around.

A particularly striking improvement in workflow is seen with trauma and emergency imaging. Consider a victim of a road traffic accident brought to a tertiary hospital at night, in the film days, obtaining a cervical spine X-ray and getting it read by the on-call radiologist could take an hour or more (shoot the film, develop it, find the doctor, etc.). With digital, the image is ready in seconds and can even be auto-routed to the radiologist's laptop at home if teleradiology is set up. This can significantly speed up critical decision-making, potentially improving patient outcomes in emergencies. Although direct studies on patient outcome measures, such as morbidity and mortality, are limited, it is reasonable to conclude that a faster diagnosis leads to improved outcomes in many situations, particularly in acute care.

Digital radiography also tends to enhance image quality consistency. Modern DR systems have a wide dynamic range and advanced processing algorithms that yield clearer images with better contrast, even when exposure conditions are not perfect. Radiologists in Nigeria have noted that digital images, especially from DR, often show details (like lung markings or bone trabeculae) more clearly than standard film-screen radiographs. (ALgorbani *et al.*, n.d.) Additionally, tools like windowing (adjusting brightness/contrast), magnification, and measurements can improve diagnostic accuracy. For example, subtle tuberculosis lesions on a chest X-ray might be missed on a low-contrast film but picked up when a digital image is windowed appropriately by an experienced reader (Cao *et al.*, 2021).

However, the transition isn't entirely without quality concerns. One issue is image processing and display variability. If monitors are not medical-grade or calibrated, the image quality might be suboptimal. Some Nigerian hospitals initially used off-the-shelf computer monitors for PACS viewing to save costs, which can impair the radiologist's ability to discern fine details. Gradually, awareness has grown about the need for proper diagnostic displays and calibration. Another issue, as previously mentioned, is radiation dose management: the phenomenon of "exposure creep." Because digital detectors can compensate for overexposure (producing a usable image even if the dose was higher than necessary), there's a risk that radiographers might use higher doses routinely, consciously or not. The low awareness of Exposure Index noted in the study is a red flag in this regard. Without understanding the EI readouts, radiographers might not realize they could reduce the dose and still get a good image (Esien-Umo *et al.*, 2023). This has direct patient outcome implications in terms of radiation safety. Addressing this requires training and possibly the enforcement of routine exposure audits as part of quality assurance programs.

What about patient outcomes and satisfaction? While hard outcome data (like reduced diagnostic errors or improved survival) directly attributable to digital vs. analog are not well documented in Nigeria, there are proxies. One is the rate of repeat examinations. With film, repeats were common due to positioning errors or exposure mistakes realized only after film processing (Hasaneen *et al.*, 2023). Digital's immediate feedback has likely cut down repeat rates significantly (an improvement not yet quantified in publications but acknowledged by practitioners). Fewer repeats mean less radiation and less hassle for patients. Another outcome is patient throughput—digital departments can handle more patients per day, meaning shorter appointment backlogs (Dackiewicz *et al.*, 2000). Patients certainly notice when they can get their X-ray done and results within the same day, as opposed to coming back in several days to pick up films. Patient satisfaction anecdotally improved when some hospitals introduced systems where patients could receive their images on a CD or via an online portal. However, those conveniences are still rare and largely in private settings (Nigatu *et al.*, 2025).

Teleradiology, as part of workflow, also has outcome implications. For rural areas that have digital X-ray but no on-site radiologist, being able to send images to a specialist in a city can lead to diagnoses that would otherwise be missed. A study in Malawi and teleradiology experiences in other African countries have shown improved diagnostic support for remote clinicians with tele-reading X-rays (Ewing & Holmes, 2022). In Nigeria, formal studies are few, but one can point to the TB screening initiatives: using CAD AI to identify TB on digital chest X-rays in communities has yielded thousands of diagnoses that previously would have been lost among undiagnosed cases (Eneogu *et al.*, 2024). This directly ties digital technology to better health outcomes (earlier TB treatment, reduced transmission).

In summary, digital transformation has largely positive effects on workflow efficiency and image quality in Nigerian radiography services, which by extension benefit patients through faster service and likely better diagnostic accuracy. Nonetheless, to fully realize improvements in patient outcomes, attention must be paid to maintaining high image quality (through QA programs) and ensuring that speed does not compromise careful image review.

### 4.6. Emerging Technologies & Innovation

As Nigeria consolidates the gains of basic digital radiography, it is also beginning to explore cutting-edge innovations that could further transform radiographic practice. Several emerging technologies are making inroads, heralding a new chapter that goes beyond simply replacing film with digital.

One of the most impactful developments is the use of Artificial Intelligence (AI) in medical imaging. Nigeria, like many LMICs, has a high burden of tuberculosis, and chest X-rays are a key screening tool. In recent years, AI-based computer-aided detection (CAD) software for TB (for example, using algorithms like CAD4TB) has been piloted. A landmark project in 2020–2023 supported by international partners deployed 10 ultra-portable digital X-ray units equipped with AI CAD software across eight states for community TB screening (Stop TB Partnership, 2023). This innovation allowed radiographic screening in remote areas with immediate AI reading of images to flag likely TB cases, which were then confirmed by GeneXpert tests (Stop TB Partnership, n.d.). The project screened over 130,000 individuals and detected thousands of TB cases that might have otherwise gone unnoticed, demonstrating the game-changing potential of combining digital X-ray with AI in Nigeria's context (Stop TB Partnership, 2023). It also showcased innovations in hardware, the use of battery-powered portable X-ray machines and solar panels to overcome power issues, literally bringing radiography to the doorsteps of underserved communities. The success of this initiative is spurring interest in expanding AI applications, perhaps to other areas like pneumonia screening, fracture detection, or even mammography in the future. That said, careful evaluation is ongoing; questions of AI accuracy in African populations and integration into clinical workflow remain research frontiers. Early user feedback from Nigeria and other countries indicates that AI tools are beneficial, but they require user training and customization to meet local needs.

Another frontier is teleradiology and telemedicine integration. While basic teleradiology (sending images for remote reporting) has been discussed, new models are emerging, such as cloud-based platforms that could connect multiple hospitals. For instance, Cloudex Radiology, a private teleradiology service, leverages cloud PACS to link Nigerian clinics with diaspora radiologists in the UK, enabling 24/7 interpretation support across time zones (Cloudex Radiology, 2021). Mobile apps now allow doctors to securely view X-ray images on smartphones; in Nigeria, some innovators are trying to package such solutions for wider use, recognizing that smartphones are ubiquitous even when dedicated PACS workstations are not. The concept of "mHealth" radiography—capturing X-ray images and reading or consulting via mobile—aligns well with Nigeria's rapid telecom growth. The 2022 South African Journal of Radiology review projected that mobile teleradiology could significantly expand radiology services in rural Africa, and Nigeria is poised to be a leader given its tech-savvy youth and entrepreneurial startups (Tahir *et al.*, 2022).

Virtual Reality (VR) and Augmented Reality (AR) are also on the horizon, primarily in the education and training space. A study in 2024 by Nwogu *et al.* explored the adoption of VR technology for radiography training in southeastern Nigeria, marking one of the first in the country to assess such high-tech educational tools (Nwogu Uloma *et al.*, 2024). Students could interact with virtual X-ray rooms and practice positioning in a simulated environment (Nwogu Uloma *et al.*, 2024). The findings indicated interest and some readiness, though they also highlighted barriers like cost and limited local expertise to implement VR at scale. The National Universities Commission's recent curriculum guidance encouraging innovation suggests that we might soon see more universities experimenting with VR as a supplement to clinical training. AR is being considered for procedure guidance (e.g., overlaying anatomical landmarks on a patient using an AR headset for interventional radiology), though these are still experimental even globally. Nigeria's innovators in health tech (often collaborations between clinicians and tech developers) are increasingly aware of these trends thanks to global conferences and the ease of information exchange. While VR/AR might not become mainstream in the next year or two due to resource constraints, their seed has been planted in Nigeria's academic circles.

All these innovations bring forth the need for fostering a culture of research and development in radiography. Encouragingly, more radiography professionals are pursuing postgraduate studies and engaging in research on digital imaging topics. Our literature review shows that while many studies are still descriptive, the scope is widening to include technology assessment and pilot evaluations (moderate-quality evidence of feasibility and user perceptions). There is a clear opportunity for higher-quality studies (perhaps randomized trials of AI use or implementation research on teleradiology models) to be done locally as these technologies mature in the Nigerian setting.

In conclusion, emerging technologies like AI-driven diagnostics, mobile teleradiology, VR training tools, and others are beginning to permeate Nigeria's radiography practice. These innovations carry the promise of bridging gaps, bringing expert analysis to remote areas, enhancing training without the need for physical infrastructure, and generally leapfrogging some development hurdles. Still, they require careful implementation and support. Nigeria's experience so far shows openness to innovation but also underscores that local context (power, cost, training) must shape how these technologies are adopted.

### 4.7. Equity, Ethics & Sustainability

No review of digital transformation would be complete without examining who benefits (and who risks being left behind), the ethical considerations, and how to sustain progress. In Nigeria's diverse and stratified healthcare system, equity is a paramount concern. The deployment of digital radiography has so far been concentrated in tertiary hospitals and urban private centers, which inherently serve more urban, often wealthier populations (Ubalaeze S *et al.*, 2024). Rural communities and smaller health facilities lag in access to advanced imaging. This digital divide can exacerbate existing health disparities: for instance, a patient in a remote village might still get an outdated film X-ray of suboptimal quality (or have no access to X-rays at all), while a patient in Abuja can get a high-resolution digital image read by an expert (Tahir *et al.*, 2022). Efforts like the mobile TB screening project with portable X-rays are one way to close this gap by bringing technology to underserved groups (Odume *et al.*, 2022). Similarly, expanding teleradiology networks has an equity dimension; enabling a rural clinic to consult with a radiologist means patients there receive a standard of care closer to that in cities. Policymakers are aware that without deliberate action, digital health innovations could concentrate in islands of excellence and not diffuse to the broader population. Therefore, there is a push (as part of the National Strategic Health Development Plan) for more equitable distribution of diagnostic facilities, possibly via federal programs that allocate digital X-ray units to state and general hospitals nationwide.

Equity also has an economic facet. Digital services can sometimes cost more to the patient. For instance, by early 2024, chest X-ray fees at major tertiary centers such as Lagos University Teaching Hospital had risen to approximately ₦6,000 per view (Medical World Nigeria, 2024), while public hospitals like FMC Bida charged around ₦2,500 per view (FMC Bida, n.d.). Meanwhile, a privately funded center that invests heavily in a DR system may charge higher fees for X-rays to recoup its investment. In a country where a significant portion of healthcare payment is out-of-pocket, this raises ethical questions about affordability (Jo *et al.*, 2024). While many patients value the better service, some might defer needed imaging if costs rise. Public sector hospitals generally keep prices regulated (an X-ray in a public hospital might still cost relatively low), but if their analog machine breaks and only a private digital facility is available, patients face a tough choice. The ideal scenario is that efficiency gains from digital will reduce costs in the long run; however, in the short term, careful health financing mechanisms (like including digital X-rays in the coverage of the nascent National Health Insurance Authority schemes) are needed to ensure the cost isn't a barrier.

Moving to ethics, digital radiography introduces concerns around data privacy and security that were not present with films. A film in an envelope is unlikely to be seen by those who shouldn't see it, but a digital image on a server or cloud could be improperly accessed if safeguards fail. There have been no major breaches reported yet in Nigeria's radiography domain, perhaps due to the limited interconnectedness so far. But as hospitals network their systems and possibly store data online, maintaining patient confidentiality is critical. Nigeria's data protection regulations (NDPR) provide a framework, but enforcement in healthcare is still evolving. Consent for procedures now tacitly includes consent for digital storage and electronic transfer of images, something patients might not be fully aware of (NDPR, 2020). Ethically, practitioners must ensure that images sent for tele-reporting are handled securely (using encrypted channels, anonymizing if needed). Another ethical aspect is the proper use of AI: if an algorithm flags a chest X-ray as normal, will a human still diligently review it, or will there be over-reliance on the machine? Ensuring that AI serves as an aid, not a final decision-maker (except perhaps in preliminary screening), is key to ethical deployment. Additionally, AI algorithms often carry biases from the data they were trained on. A pressing research question is how well they perform on Nigerian patients. Using an AI without validation could lead to missed diagnoses in populations that diverge from the training set. Thus, local validation studies (which are ethically necessary to ensure no harm) should precede widespread AI use (Backman, n.d.).

Sustainability is the final crucial piece. How can Nigeria ensure that the digital gains in radiography are maintained and expanded in the long term? This has financial, technical, and social components. Financially, there needs to be continuous investment not just in equipment procurement but in maintenance and eventual replacement as technology evolves. A digital X-ray unit has a lifespan, and planning for upgrades is important (European Society of Radiology (ESR), 2014). International donors have kick-started many digital projects, but reliance on external funding is not sustainable. Building local ownership is therefore essential. The federal government could commit a dedicated portion of its annual health budget, aligned with the Abuja Declaration's call for at least 15% of national budgets for health, to support radiology infrastructure maintenance and upgrades (Olorunfemi, 2023). Indeed, the proposed 2025 healthcare budget reflects a 58% increase in sector funding, offering a potential funding stream for ongoing radiology investment (dRPC, 2025). Encouraging public-private partnerships could also be beneficial, as private firms would support technology in public hospitals in exchange for specific concessions, thereby creating a win-win situation to ensure that systems remain operational.

From a technical sustainability standpoint, developing local expertise is key. Nigeria should aim to have its cadre of PACS administrators, biomedical engineers, and even software developers who can service and innovate on these systems. Sending engineers for specialized training or inviting manufacturers to host workshops could reduce dependency on flying in foreign experts for every major issue. Encouragingly, the younger generation of radiographers and radiologists is quite tech-literate; some radiographers have learned basic coding or IT troubleshooting out of necessity and interest, becoming de facto support personnel. Institutionalizing such roles (e.g., having an IT unit within the radiology department) would go a long way.

Finally, we consider the social sustainability and acceptance by patients and communities. Patients in Nigeria have consistently reported high satisfaction with digital radiography services, often citing streamlined workflows and clearer images as key benefits; a study at the National Orthopaedic Hospital, Igbobi Lagos, found that 87% of patients rated digital imaging services as "very satisfactory" following the transition from film-based systems (Efeoghene *et al.*, 2021). Public trust in these services remains high as long as they are delivered competently and on time (Mitchell *et al.*, 2024). Maintaining that trust means continuously monitoring the quality and addressing any issues swiftly.

In summation, equity, ethics, and sustainability intertwine as both challenges and guiding principles for Nigeria's digital radiography journey. The aim should be to ensure that the benefits of technology reach everyone, that they are used responsibly and safely, and that the systems in place today will endure and evolve for tomorrow.

Limitations

While this review endeavored to be comprehensive, several limitations must be acknowledged. First, the available literature on digital radiography in Nigeria is limited in scope and quality. Much of the evidence comes from single-center studies or expert opinion pieces, with few large-scale or longitudinal studies. This constrains the generalizability of certain findings. Second, data from the early 2000s are sparse, making it difficult to quantify baseline metrics of analog practice for comparison. We often had to rely on anecdotal or retrospective accounts to reconstruct the adoption timeline. Third, as a narrative review, our synthesis may be subject to selection bias; relevant unpublished experiences or non-indexed reports might have been missed despite broad searching. Fourth, the fast-evolving nature of technology means that by the time of writing (2025), some cutting-edge developments may not yet be captured in literature; we interpolated recent trends (e.g., AI pilots) with caution, acknowledging that outcome data on these are still emerging. Finally, our discussion of impacts on patient outcomes is somewhat inferential due to a lack of direct studies in Nigeria linking digital radiography to clinical outcomes. Future research, including multi-center outcome evaluations and cost-benefit analyses in the Nigerian context, will be valuable to address these gaps. Despite these limitations, we believe the review provides a reasonably up-to-date and contextual picture of digital transformation in Nigerian radiography, offering insights that can guide stakeholders in practice, policy, and research.

## 5. CONCLUSION

Nigeria's voyage from analog to digital radiography is a compelling story of progress amid constraint, a bit like upgrading the engine of a moving vehicle. Over roughly two decades, we have witnessed Nigerian radiography departments transition from darkrooms and wet films to computers and cloud storage. This comprehensive review has charted that trajectory, elucidating how technological adoption, though delayed, eventually gained momentum and is now redefining imaging care in the country. The adoption trajectory shows a classic late-mover pattern: slow uptake at first, now accelerating as benefits become undeniable and as costs gradually decrease. Early deficits, such as the total lack of digital systems in entire states as of 2011, are giving way to a new normal where digital imaging is expected at modern healthcare facilities.

The drivers and barriers of this transformation are multifaceted. On one hand, improvements in workflow efficiency, image quality, and accessibility of expert interpretation (via teleradiology) strongly push the system toward digital solutions. The advantages for patient care, quicker results, fewer repeat exams, and better-informed diagnoses align well with Nigeria's healthcare priorities of improving quality and access. On the other hand, challenges like unreliable electricity, high equipment costs, and maintenance hurdles serve as sobering reminders that context matters; a high-tech machine is only as good as the infrastructure and people supporting it. We discussed how institutions ingeniously cope with these challenges: installing generators and solar backups, piecing together funding from diverse sources, and creatively training staff. These "Nigerian factors" highlight that digital transformation is not merely a tech upgrade but an organizational and economic endeavor.

The policy environment play a crucial role in digital radiography, hence we recommend these:

• Codify telemedicine & teleradiology in health law: define licensure, cross-jurisdictional reporting, and medico-legal validity of remote reads.

• Issue national PACS & data-security standards: mandate NDPR-compliant encryption, role-based access, and routine audit trails for all digital-image archives.

• Recognize radiographer preliminary reporting in radiologist-short settings, with clear scope, mandatory EI-based QC training, and liability guidelines.

• Embed digital-imaging competencies in licensing: make exposure-index use, display calibration, and dose-audit skills compulsory CPD for radiographers/radiologists.

• Create a standing Radiology Policy Forum (FMoH + RRBN + ARN) to update guidelines annually and fast-track adoption of emerging tech (portable DR, AI-CAD).

Looking ahead, Nigeria seems poised not only to consolidate basic digital radiography but also to leap into advanced innovations, making this an exciting juncture. The early success of AI in screening and the experiments with VR in education are harbingers of an even more digital future. These could significantly augment capacity; imagine semi-automated detection of diseases and highly trained professionals churned out by simulators, but they require careful nurturing in terms of training, validation, and resource allocation. All stakeholders must closely monitor equity and ethics. A digital revolution that leaves rural areas behind or compromises patient privacy would undermine the very goals of healthcare. Hence, deliberate efforts to extend digital services to underserved communities (such as through mobile units or subsidized government programs) and to enforce ethical standards (like informed consent and data security) are non-negotiable as the field advances.

In conclusion, the digital transformation of radiography practice in Nigeria is well underway and largely positive in its impact. The country has moved from being a late adopter to an innovator in certain niches, demonstrating resilience and ingenuity. Yet, it is a work in progress, much like a high-resolution image still rendering; some parts are crystal clear (the benefits, the success stories), while others are coming into focus (policy frameworks, uniform nationwide adoption). The collective experience thus far yields a clear lesson: technology in healthcare is most effective when matched by investment in people and systems. For Nigeria, continuing on this path means acquiring new tools and building a supporting ecosystem through training, infrastructure, and supportive policy. If these elements coalesce, the vision of a fully digital, efficient, and equitable radiography service across Nigeria is not a distant dream but an achievable reality on the horizon. In the spirit of Nigerian optimism and pragmatism, one might say we have "tested the mic" on digital radiography; now it's time to turn up the volume for the benefit of all.

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