

The Significance of Blockchain Adoption in Radiotherapy Management in Low-Resource Setting

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Abstract:

Radiotherapy (especially teleradiology, or remote radiology service) is becoming indispensable. Enabling adaptive radiotherapy (AR) is transformative, and effective implementations face a complex, multi-faceted set of challenges interconnected across clinical, technical, regulatory, and ethical dimensions that threaten to slow adoption and limit efficacy. Addressing these barriers in radiotherapy lifecycle management is of utmost importance as they are vital for establishing sustainable, inclusive, and effective radiotherapy ecological systems. This study explored how blockchain technology, a decentralized and immutable ledger, enhance radiotherapy management. This study explores integrating blockchain technology into the radiotherapy ecosystems to address data access, security and privacy challenges. Blockchain's transparency, confidentiality, and decentralization offer significant potential benefits in the radiotherapy domain. In the present paper, adopting a grounded theory method, we propose a meta-methodology for blockchain adoption and adaptation that guide the transition from initial awareness to post-adoption maturity. The contribution provides evidence-based guidance for policymakers and administrators.

Keywords: blockchain technology; adaptive radiotherapy; grounded theory.

1. INTRODUCTION

Radiotherapy is essential for cancer treatment, yet many resource-constrained settings face significant barriers in accessing the services. The future of radiotherapy healthcare benefits is being shaped at the intersection of technology and innovation. Disruptive digital health technologies such blockchain are reshaping how cancer patients interact with health professionals, how data are shared among providers, and how treatment plans and health outcomes are determined. Research (e.g., Nuhu et al., 2020; Aruah et al., 2023) indicates that radiotherapy access gap is wide, with some sources suggesting that approximately 90% of cancer patients in low- and middle-income countries (LMICs) who need such services do not have access to it. A large deficiency exists for radiation oncological services in Nigeria (Adewuyi et al., 2025), Cameroon (Mapoko et al., 2023) and many other African countries (Mallum et al., 2024). The reasons for this are multifactorial, including underinvestment in therapy equipment, lack of planning and evaluation, and manpower to function optimally (e.g., Zubizarreta et al., 2017; Akinwande et al., 2023; Mapoko et al., 2023; Adewuyi et al., 2025; Ogunniyi et al., 2025), and psychosocial factors like depression, anxiety, marital status, social status, religious belief (Evbuomwan et al., 2024).

According to the International Agency for Research on Cancer (IARC) publication, the global cancer cases are predicted to rise from 20M million in 2022 to 32.6M in 2045. Almost half of these patients will require radiotherapy, posing a daunting capacity challenge in some countries (Chandra et al., 2021). Globally, decades of improvements in digital technology have improved the capacity, planning and delivery of radiotherapy, making it more precise and accurate (Connell & Hellman, 2009). Today's treatment paradigm is moving from "what you see on paper is what the patient receives" to "adaptive radiotherapy and real-time motion" adaptation (Huynh et al., 2020; Bertholet et al., 2019).

Adaptive radiotherapy (ART) and radiotherapy management (RTM) system is a multidisciplinary team practice and typifies a complex system. Understanding and managing the interactions among subsystems and components is critical not only to ascertain objective outcomes, but to maintain the integrity of the whole (Amaechi & Counsell, 2014). It is established fact that prevention, early detection, and treatment are vital to successful cancer control. Despite this vital understanding, access to effective radiotherapy services is limited or non-existent, especially in resource-limited settings. The challenges within these environments are multifaceted. The few available facilities lack essential equipment, such as advanced planning systems, and supportive technologies that allow for precise treatment delivery,

availability of effective data (Kumar, Mehta, & Chaudhary, 2022). Compounded by socioeconomic factors, the availability of experienced radiation oncologists and medical physicists is also jeopardized, creating a gap in the knowledge and practices necessary for effective treatment planning (Sikora, Ratanatharathorn & Sweeney, 2020). Moreover, limitations in logistics often lead to delays in treatment initiation, which can adversely affect patient outcomes (Bhandari, Haynes, & Sulman, 2021), and poor radiation oncology awareness and literacy, complex workflows, communication problems, lack of cooperation among stakeholders, high costs, and poor security of data (Kenamond et al 2022). Other key challenge includes the privacy concern which restricts data sharing between various organizations based on legal and ethical problems (Kalidindi & Srinivasu, 2025). These challenges results in a complex, multistage radiotherapy structural components and process requirements.

Developing and implementing radiotherapy solutions that evolve with patients' needs is critical and are paramount for overcoming these barriers in such a continuously changing environment. Innovations that can speed up patient care, empower the therapists, and other stakeholders' and reduce the transaction costs are in high demand and will continue to be so in foreseeable future. Akintunde and colleagues conducted a narrative review and concluded that digital health can reduce the need for people traveling long distances for regular healthcare services in many African countries, where the scarcity of adequately staffed medical facilities, primarily located in major urban centers (Akintunde et al., 2021). Initiatives aimed at fostering collaboration between institutions in high-income and low-resource countries can facilitate knowledge transfer and enhance local capacity (Jaffray, McKenzie, & Tan, 2021). Different researchers (e.g., Alexander et al, 2019; Architha & Edwin, 2021; McBee & Chad, 2020; Bercovich & Marcia, 2018) have observed the increased usage of digital data in cancer related medical imaging, and the needs for innovations that enhances the solutions.

Blockchain technology (BCT) is identified as an innovation capable of providing decentralized communication of data and information between healthcare facilities, professionals, and patients (Ghadi et al., 2024). Propagating knowledge about the applicability of blockchain is critical because the radiotherapy field is evolving from a purely image-based specialty into a data-driven one, where data integrity, security, and interoperability are paramount. Against this background, this paper aims to:

- Explores potential applications and implications of blockchain technology in the radiological environment especially in resource-limited settings.
- develop a systemic framework for preparing organisation for a strategic adoption and adaptation of blockchain technology within a radiotherapy ecosystem.

2. Literature Review

In the next subsections, the building block of BCT is presented, and sample applications in radiotherapy research are reviewed.

2.1 Desirable Properties of Blockchain for Radiotherapy Services

Since the introduction of the BCT in 2008 by Satoshi Nakamoto, the technology has been used in various industries such as business, finance, and healthcare. Blockchain is a distributed database that maintains a continuous list of records, and a collection of fundamental components underpins the technology, which collectively establishes its unique attributes of transparency, decentralization, and security (Alabdulwahhab, 2018; Rathee et al., 2019; Zhao et al., 2020; Bai & Sarkis 2020; Zarrin et al., 2021; Bai, Sarkis, & Xue, 2024; Hariyani et al., 2025). A key feature of blockchain technology is the immutability of the data; blocks are incorporated in a permanent manner even in the presence of attack (Crosby, 2016; Narendra Kumar et al., 2025). The blockchain protocol and in-built cryptographic tools prevent pre-existing data from being tampered with, thus ensuring data integrity and protection against fraud. This can be useful in processes requiring data tracing, e.g., in clinical audit or for tracking of therapeutic goods along a supply chain (Jamil et al., 2019; Haleem et al., 2021). The innovation of smart contracts – programs that automate pre-determined instructions and conditions on the blockchain is another backbone of the technology. In the radiotherapy setting, smart contracts could facilitate transfer of images and other data between institutions on the blockchain network, skipping the need of an intermediary to fetch data for transfer, streamlining the necessary communication between service providers. In another settings, radiologists and other involved clinicians can attend to their patient via information recorded on the blockchain and have smart contracts provide an array of services such as booking patients for ongoing routine follow-up without the need of a booking administrator.

Blockchain operates in a flexible landscape that allows for different types of network configurations [...] may be public or private, permissioned or permissionless, or driven by tokenized crypto economics or tokenless. However, this distinction can be nuanced, as there are blockchains that blend elements of to leverage their respective advantages (Garriga et al., 2021). Blockchain offers security through cryptography, transparency via immutable shared ledgers, decentralization to prevent single points of failure, and automation with smart contracts. Comprehending these components is essential for understanding how blockchain has the potential to revolutionize many fields. Different methods, theories and perspectives have been applied in academic and industry studies to understand BCT (Melisa Petra Benchis et al., 2025; Nsowah et al, 2025). In their review study, Ghorashi et al (2023) provide a strengths, weaknesses, opportunities, and threats (SWOT) analysis discussing the internal strengths and weaknesses as well as the external opportunities and threats in relation to blockchain technologies.

2.2 Current State of Blockchain Radiation Therapy Management

Although there is an increasing interest in blockchain technology from healthcare, there are limited use cases and research on the use of blockchain in radiotherapy compared to other industries. An overview of different blockchain applications is presented in (Fraga-Lamas et al., 2024). Radiotherapy consists of three crucial steps: preparation, delivery and evaluation, and each step can be digitalized, from scan simulation (MRI, CT, or ultrasound), oncology imaging, planning, dose verification, and image guidance to treatment delivery. In addition, ensuring the security, privacy, and accuracy of patient data while sharing them among multiple specialists is a challenging task in radiotherapy. This is requirement where BCT offers a robust solution (Xi Peng et al., 2022).

Blockchain supports cross-platform safe sharing of radiotherapy resources, streamline interoperability, empower patients, and offer transparent impenetrable security capacity, boost precision and enhance patient outcomes (Zhu & Yu, 2023; Tagliafico et al., 2022; Tomihama et al., 2025; Tadeballi & Amar, 2025). Myeong and Ram (2025) introduces a blockchain-based protocol leveraging Zero-Knowledge Proofs (ZKP) to enable verifiable yet privacy-preserving health data sharing. The protocol is built on a permissioned Ethereum blockchain, the protocol ensures that medical data validity can be confirmed without disclosing sensitive content.

Tomihama et al., (2025) conceptualised that the integration of BCT with teleradiology can be combined with multimodal large language models (LLMs) to improve the automation and standardization of radiology reporting. According to Nezameslami et al (2025), by utilizing blockchain's decentralization, transparency, and security features, a blockchain-based EHR system can enable real-time data sharing, improve patient care coordination, and build trust within the cancer care continuum. BCT promotes seamless information sharing by enabling secure and efficient sharing of EHRs among various healthcare providers, which is crucial in oncology, where patients often consult multiple specialists (Singh et al., 2025). Othman & Getahun (2025) developed a system named EHRGuard: Enhancing Privacy and Security of Electronic Health Records through Blockchain Technology which leverages BCT to address key challenges in the management of EHRs, with a focus on improving privacy, security, fosters trust and efficiency, and interoperability in healthcare data systems for consumers.

In another study, Bhasker et al (2025) proposes the Federated Blockchain-IoT Framework for Sustainable Healthcare Systems (FBCI-SHS) for a secure health monitoring system further showing the versatility of BCT. A key challenge in radiotherapy ecosystems is preventative maintenance which is imperative for ensuring the longevity and reliability of diagnostic medical imaging equipment. To solve the challenge, Omar et al (2024) proposed a solution that leverages BCT, smart contracts, IPFS, and timer oracles to promote transparency, accountability, and traceability in maintenance operations. Dubovitskaya et al research proposed ACTION-EHR as a radiotherapy clinical application that uses BCT platforms to provide patients with control over their health data, improve clinical coordination, and support future advancements by creating a trustworthy and verifiable data infrastructure (Dubovitskaya et al., 2020). Discussed in the context of managing EMR for cancer patients, the authors (Kamau et al., 2018) talked about the relevance of blockchain in managing distributed information in EMR, providing the security and trust mechanism for sharing information.

The authors (Azogu et al 2019; Watat et al., 2025) proposed different conceptual frameworks for the adoption of BCT in healthcare information management systems. The authors (Adamu Sa'ad Madaki et al., 2020) investigated the management of medical records in 3 teaching hospitals in Nigeria and recommends a framework built on three pillars: healthcare systems, security, and blockchain technology. In 2018, Patel developed a framework using BCT to permit patients to allow electronic access to their medical imaging data preserving security [Patel, 2019]. According to the

author, the goal of blockchain usage was to set a series of predetermined endpoints to retrieve imaging studies and patient data ensuring that only authorized entities could have access only to the patient's desired data [Patel, 2019].

2.3 Challenges of Blockchain Adoption

Despite blockchain's enormous potential for the radiotherapy related applications, prior researchers have reported several technological, organizational, regulatory, and economic" barriers hindering and limiting the technology's adoption. Following a thorough examination of the prior researchers' articles, eight barriers to blockchain adoption were identified and validated by twelve experts who participated in the e-Delphi interviews.

Regulations are pivotal in shaping the adoption of innovative systems, with clear and supportive policies encouraging its integration across industries, while ambiguity or restrictive laws can hinder its progress (Yeoh, 2017) and lack of a regulatory framework leaves businesses uncertain about compliance (Alzahrani, Daim, & Choo, 2023; Takashima et al., 2018). Scalability is another important challenge of blockchain. This is related to transaction throughput and latency, storage capacity of blockchains, block sizes, number of nodes connecting to the blockchain, which may impact the performance (Shuaib et al., 2019; Maesa & Mori, 2020; Khan, Jung, & Hashmani, 2021; Khan et al., 2023; Kim, Kwon, & Cho, 2025). Correct data is a must have in RTM settings. Ability to correct incorrect data is perquisite to any RTM digital application. This is sometimes difficult with BCT. Literature shows that BCT is designed to be immutable, meaning that once data are recorded on the blockchain, it cannot be easily modified or deleted (Khan et al., 2021). As a result, incorrect data can persist and be visible in the system, potentially leading to inaccurate analyses or conclusions. High energy requirement, installation costs, as well as the stringent computer requirements to support use (Kasyapa and Vanmathi, 2024) are also important challenges. However, a good consensus mechanism selection has proved that less energy can be achieved (Bada et al., 2021; Asif & Hassan, 2023). Given the lack of clear implementation standards, health care organizations may have hesitancy in sharing patient information with BCT (Kasyapa and Vanmathi, 2024). Patients may likewise be hesitant to accept and participate in BCT-enabled systems. Privacy concerns arise with BCT due to its inherent transparency, which can expose sensitive data (Khan et al., 2023; Wenhua et al., 2023; Mohanta et al., 2019).

The shortage of skilled professionals is a significant challenge in the successful implementation and management of RTM digital transformation project in countries like Nigeria. This skills gap will stay as a considerable barrier to the widespread adoption of blockchain across the RTM ecosystems. The Bazel et al (2025) study shows that technology trust, information transparency, disintermediation, cost-effectiveness, top management support, organizational readiness, partner readiness, technology vendor support, and viability significantly and positively influenced the intention to adopt blockchain-based health information systems in hospitals. According to Abdul-Moheeth et al (2022), BCT faces challenges of recognition, trust, and usability to widespread adoption as other novel interventions.

Interoperability, or the ability of different blockchain platforms to communicate and interact with each other, is a significant challenge (Anthony Jnr, 2024; Abdulrahman Alzahrani et al., 2025). Radiotherapy (especially Teleradiology or remote radiology service) oncology practices face increasing challenges in cost, data security, and operational efficiency. Implementation of a blockchain is strongly accepted as offering transformative potential for managing clinical data, informed consent, and governance. Inadequate infrastructure is the most critical issue that must be addressed to ensure successful adoption (Wazhi et al., 2024).

A 2024 healthtechafrika.org publication said that in the "context of the African radiotherapy ecosystem, the inherent rigidity of network topology in many blockchain frameworks presents a critical challenge, primarily due to fragmented infrastructure and inconsistent internet connectivity."

3. Materials & Methods

The overarching objective of this paper is the construction of a meta-methodology for blockchain adoption and adaptation which involves a structured, multi-layered approach to understanding, implementing, and modifying blockchain technology within radiotherapy organizational and supply chain contexts. Considering the study's objectives, constructivist grounded theory (GT) using exploratory literature review and e-Delphi technique process is considered most appropriate. GT is an inductive research methodology that focuses on generating theories directly from data (e.g., Strauss, 1987; Glaser & Strauss, 2017). To apply GT, a literature review was conducted. Systematic reviews serve as a foundational methodology within healthcare research, enabling a rigorous synthesis of existing literature to address

specific research questions. This approach aggregates findings from previous studies to provide a comprehensive understanding of a topic, as demonstrated by Kuo et al. (2017) in their examination of blockchain adoption in the healthcare sector. By analysing both conceptual and empirical research, the review consolidated current understanding and key themes from prior scholarly work. The specific steps taken in this study are shown in Fig. 1.

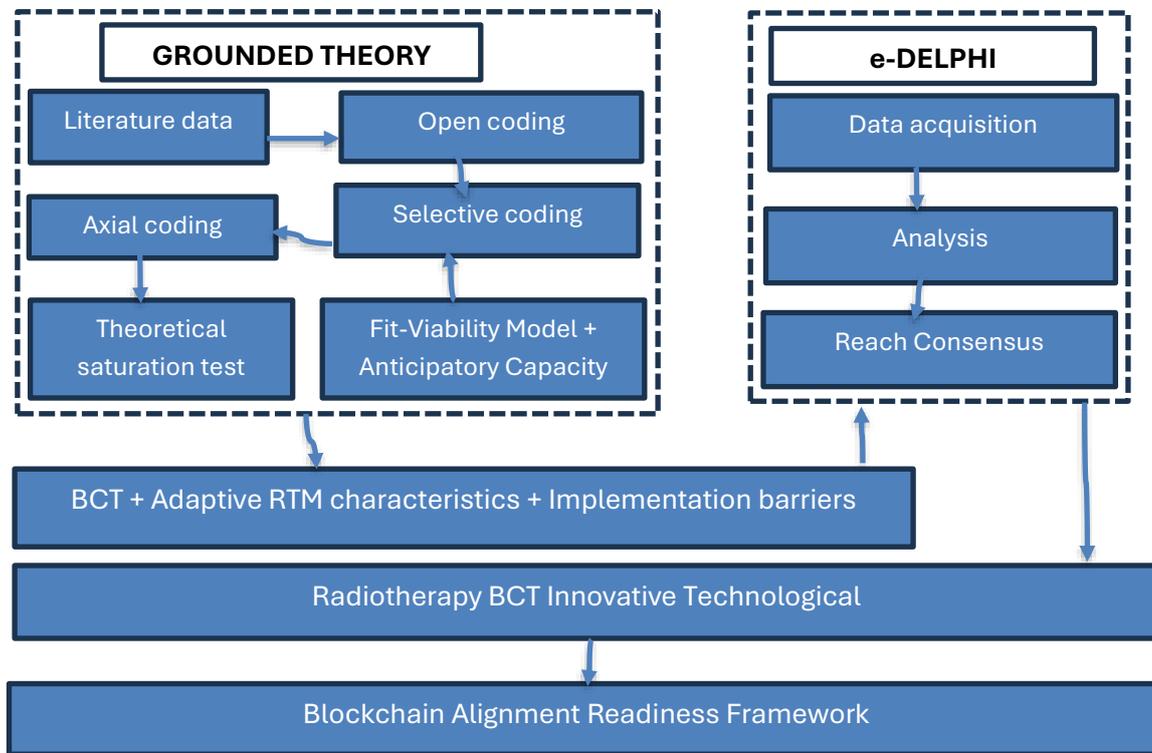


Figure 1. Research methods; step-by-step.

In this study, the specific processes used to conduct the research using GT were as follows: literature data collection, open coding, axial coding, selective coding and a theoretical saturation test. The framework created by Arskay and O’Malley (2005) was used for this scoping review. For this study, searches were conducted for the research questions using Google Scholar, Scopus, and Web of Science (WoS) databases in December 2025.

Based on the works of (Strauss, 1987; Glaser & Strauss, 2017), we defined ‘Open coding’ as the process of labelling, conceptualising and categorising primary documents to form categories. A ‘category’ is a structural concept with the same properties and the common property on which things need to be categorised. All the research team were involved and conducted open coding. ‘Axial coding’ is the process of summarising and analysing the inner logic of all the obtained categories with higher precision and depth based on open coding, finally forming the main categories. ‘Selective coding’ is a deeper comparison, analysis and abstraction of the main categories compared to the primary axial coding. Through selective coding, a new theoretical framework is constructed by extracting the core categories with high generality. A theoretical model constructed from existing data is considered to have reached ‘theoretical saturation’ when no new categories can be obtained after introducing new data. The research team performed open coding of all studies obtained, and the results showed that no new categories is possible. Therefore, it can be concluded that the theoretical model constructed by this grounded theory passes the theoretical saturation test.

The theoretical model informs the development of the next step. The Delphi study design, including expert panel composition, number of rounds, and consensus definition, was predetermined following the recommendations for Conducting and Reporting Delphi Studies (CREDES) (Jünger et al., 2017). Experts were recruited through purposive sampling based on their expertise, profession (radiation oncologists, physicists, and implementation scientists), and geographical representation (Keeney, McKenna, & Hasson, 2011). This study was designed as a multi-center, assessing participant’s familiarity of and current perspectives on the applications of BCT in medical imaging. The study context was a cancer specialist hospitals and research institution in Nigeria and Cameroon. All participants were informed that their participation was voluntary and anonymous. Following the Delphi methodology in health sciences (Niederberger

& Spranger, 2020), this study was structured into three consecutive rounds. Similar to collecting interviewees' input, experts were asked to assess the protocol based on its relevance and applicability. Additionally, experts were requested to propose improvements to the implementation protocol throughout all three rounds. A 5-point Likert scale, ranging from very irrelevant (=1) to very relevant (=5), was used to score each item of the protocol (Keeney, McKenna, & Hasson, 2011). The idea was to screen and validate the information identified in the first phase. "All items were assessed in rounds 1 and 2 by the same Delphi panel to maximise consensus. Items that did not achieve consensus in round 2 were carried forward to round 3, specifically to the individuals who disagreed. In each round, experts were asked to (re-)evaluate and rate each item, with feedback provided on the calculated scores from the previous round, using the same 5-point Likert scale". Each round was conducted using an online questionnaire facilitated through Microsoft Forms. Data analysis was performed in Excel. Consensus levels for each item were determined based on the median score, interquartile range (IQR), and percentage scoring on a 5-point Likert scale.

4. Findings

In the healthcare system in Nigeria, Cameroon and the rest of Africa, BCT is being explored and piloted in several ways to address radiotherapy and other healthcare related challenges. Blockchain possess multiple features that make them general-purpose tools in enabling transparency, coordination, and information sharing. In this section, we share our findings on the potential and actual applications of blockchain

4.1 How blockchain enhances the implementation of radiotherapy management

Blockchain technology in radiotherapy is "emerging as a critical, innovative, and secure framework, designed to enhance data integrity, patient privacy, and secure, cross-platform information sharing" (Jian Zhu & Jinming Yu, 2023). A typical blockchain-based radiotherapy cycle (Figure 2) includes the following stages: Data Acquisition, Secure Data Transfer, blockchain integration, Smart Contract Execution, Real-Time Visibility, and Lifecycle management | Patient Outcome. While ensuring security, this model is independent of commercial platforms and is more easily promoted among radiotherapy units. Since the system is connected to the blockchain network, all of these activities will be securely recorded in the blockchain. This ensures that no physician or individual can manipulate or delete their opinions or diagnoses.

The literature review highlighted that radiologists should stay informed of BCT given its current capabilities, ongoing improvement, growing acceptance across disciplines, and unique potential to support the needs of the adaptive radiotherapy.

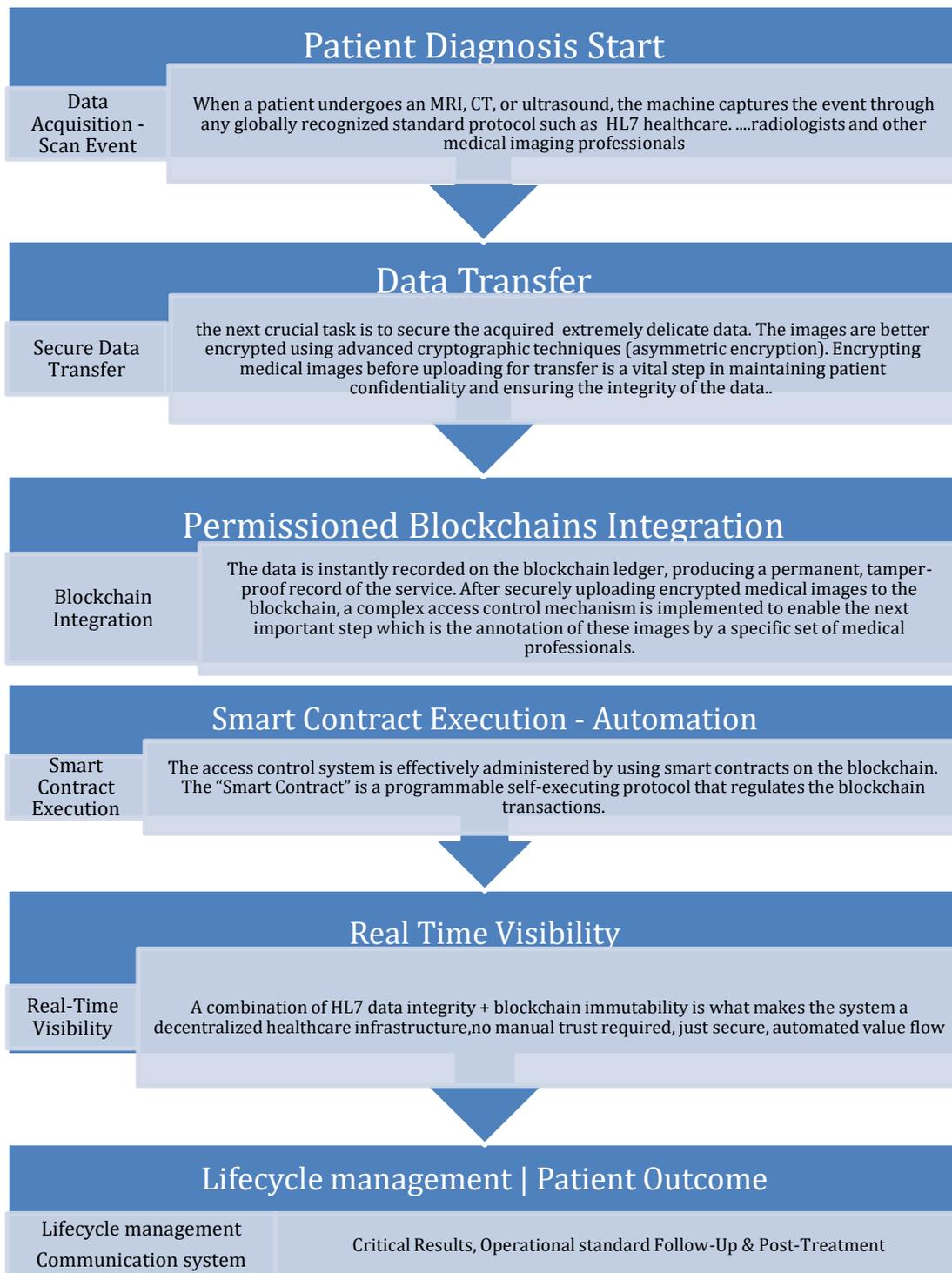


Figure 2: A typical blockchain-based radiotherapy (RT) cycle

Based on insights from the interviews and the steps derived from the literature review, blockchain’s capacity to transform radiotherapy solutions can be categorized into six applications’ area: secure & immutable data management, data sharing & interoperability, patient empowerment & consent management, streamlined clinical trials & research, automation, and quality control & error reduction (Figure 3).

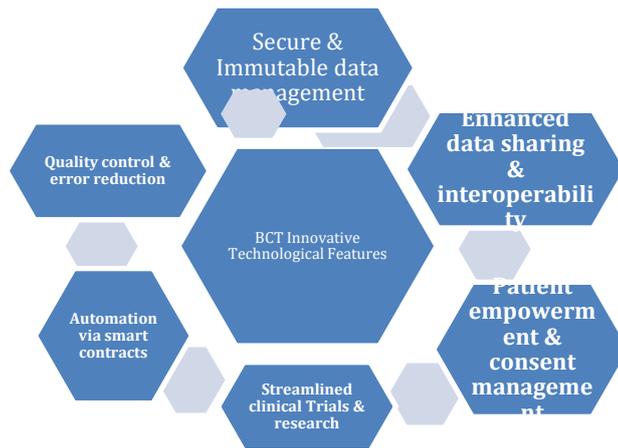


Figure 3: Radiotherapy BCT Innovative Technological Features

Secure immutable data management: application must provide a tamper-proof and traceable record of a patient's entire radiation oncology journey, from initial imaging and diagnosis to treatment delivery and follow-up. The strength of BCT provides a shared, immutable and transparent history of all the transactions to build applications with trust, accountability and transparency. Although not every blockchain guarantee to be immutable, the PoS blockchains are widely known to be.

Enhanced data sharing & interoperability: the BCT contract layer and others has the capacity to facilitate the seamless and secure exchange of complex data (e.g., medical images, radiation plans, dose distributions, and genomic data) among different hospitals, clinics, and researchers. This is particularly useful when patients receive treatment at multiple centers, ensuring all providers have access to a complete and current medical history. The scalability of blockchain solutions is essential for accommodating various healthcare providers, facilitating seamless information exchange, and ensuring continuity of care (Nezameslami et al., 2025) and BCT supports for cross-platform safe sharing of radiation therapy resources (Zhu & Yu, 2023) is essential.

Patient empowerment & consent management: Blockchain have proven that it can secure informed consent, protocol changes, and primary endpoints with an undeniable, time-stamped record, creating unparalleled trust among regulators, sponsors, and the public. BCT will provide patients with greater control over their health data and can contribute to managing who accesses their information through secure consent mechanisms, often using private keys.

Streamlined clinical trials & research: by using a decentralise, cryptographic ledger, providers can create a record of clinical trial milestones, protocols, and critical data points that is truly immutable and publicly auditable. Decentralization architecture breaks down data silos between different RTM providers and research institutions, allowing for secure, real-time sharing of comprehensive patient records and large datasets (like medical imaging files) among authorized stakeholders.

Automation via smart contracts: Adaptive RTM is better supported by incorporating information systems that facilitate intelligent imaging, enable clinical decisions automation, evidence based electronic health records, streamline operations, facilitate better integrated communication and collaboration, and capable of adapting to different environments. Smart contracts facilitate automation of various administrative tasks, such as managing patient enrolment in clinical trials, tracking medication adherence, reducing delays and administrative burdens.

Quality control & error reduction: BCT enabled solution minimizes the risk of human error and data manipulation across the RTM network as intermediaries are eliminated. The decentralised structure enhances accountability by making each action traceable to its source, removing the need for oversight from a centralised authority. This closely aligns with established quality control mechanisms, which focus on monitoring and assuring the reliability of processes and products (Chang et al., 2019).

4.2 Conceptual Resource Sharing Radiotherapy Platform

The trust building, robustness/fault tolerance, security, and redundancy features of blockchain (Ruoti et al. 2020) make it a viable platform for resource sharing among actors operating in different contexts. Such a platform is a teleradiology platforms which enable the remote transmission and interpretation of medical images (X-rays, CT scans, MRIs, ultrasounds, routine and specialized procedures) among different actors. Teleradiology is a modern radiotherapy solution mainly used to address specialist shortages, improve access to expert, timely, and 24/7/365 reporting services for

hospitals, particularly in rural or underserved areas. Figure 4 represents the developed architecture that embeds BCT for Teleradiology. The artefact represented by Figure 4 is a conceptual model with distinct constructs used to share resources using a BCT platform. This model consists of users (radiologists, physicians), organizations (hospitals), blockchain ledger, DICOM repository, and blockchain networks. A key component is an immutable audit trail (blockchain ledger) which is a dynamic secure technology that records a cryptographic hash of each image and patient report, and Picture Archiving and Communication System (PACS) for storing all medical images. Another significant component is smart contracts used for managing automated workflow. For instance, an ethereum-based, self-executing contracts has capacity to manage workflows such as automatically transferring images to the right radiologist, confirming receipt, and verifying the authenticity of images. The blockchain controls and manages access to medical images stored in the onsite PACS. In that process, a registered radiologists can request access to medical images. Peer nodes in the hospital verify the authenticity of the access request. If access is granted, the radiologist will be provided with a link to view the requested images.

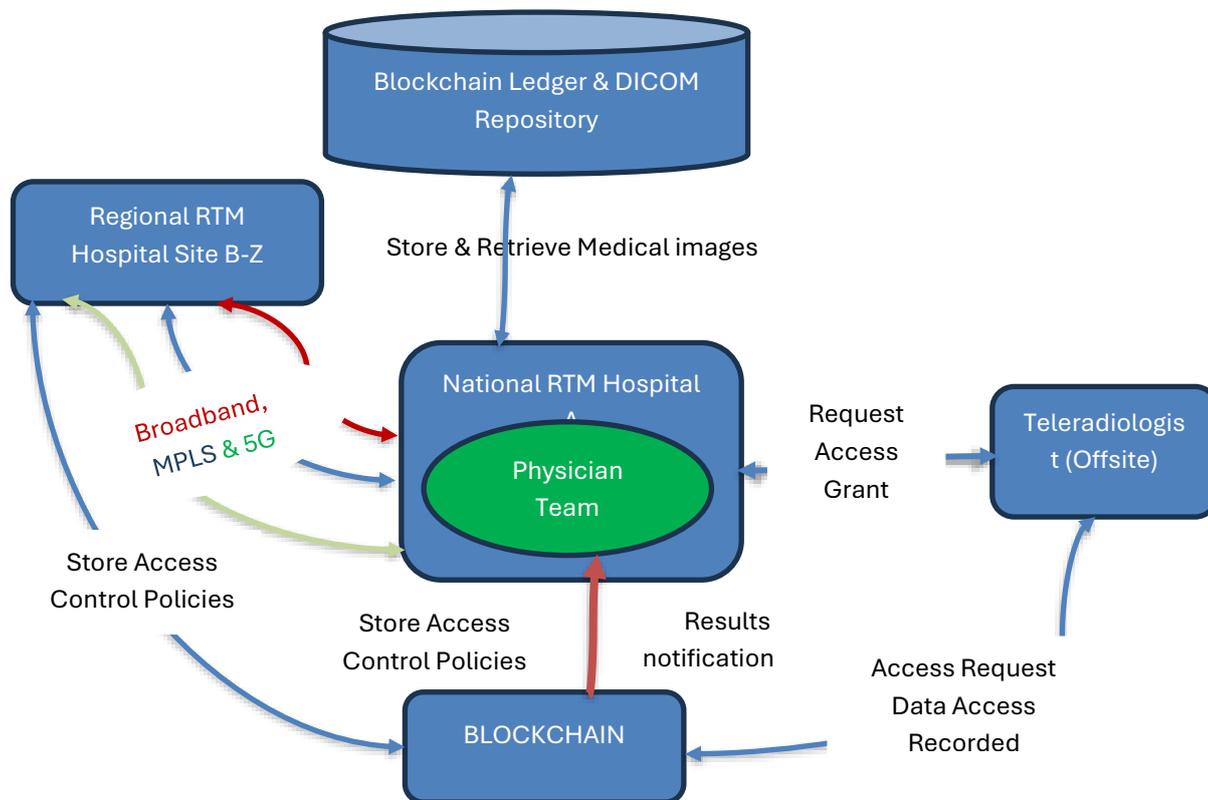


Figure 4. BCT-Enabled Teleradiology architecture

A web-based application that allows radiologists and other interested stakeholders to visualize images and interact with the platform will be available, and a capable message-oriented middleware will be used to manage communication between the blockchain, PACS, and users, allowing for secure, real-time updates and synchronization. Application of BCT has demonstrated its viability as a platform for multiple actors to share resources in a secure manner if these actors have a shared goal and an entity exists that is trusted to manage the platform.

4.3 Blockchain Radiotherapy Alignment Innovation

After developing and introducing new technologies, it is important to consider the adoption rate of the platform utilizing the users' acceptance (Taherdoost, 2022). Understanding whether people accept new specific innovation or not as well as the reasons behind that can help stakeholders acquire better results in the innovation process (Taherdoost & Masrom, 2009). The acceptance rate helps decision-makers in the development step to consider the problems that users may face. This factor is illustrated as an important antagonism to the term refusal, which also means the decision to apply a technology/innovation positively (Taherdoost & Madanchian, 2020). Many researchers have employed list of factors

to consider in their BCT adoption models and analyzed the collected results to obtain the most significant factors among them. The common blockchain acceptance frameworks include *Technology Acceptance Model (TAM)*, *Technology–Organization–Environment (TOE)*, *Diffusion of Innovation (DOI)*, *Unified Theory of Acceptance and Use of Technology (UTAUT)* and *extended TAM/TOE*.

Implementing an alignment of BCT and RTM is a challenging process that requires careful planning, specialized expertise, and a willingness to overcome technical, regulatory, and implementation-related challenges. In this section, a framework for blockchain radiotherapy management system readiness needs are defined.

The proposed model is illustrated in Fig. 5 and represents an innovative integration of the Fit-Viability Model (FVM) and anticipatory capacity. The FVM is an organizational technology adoption model used to assess the potential success or failure of implementing new technologies based on two key dimensions: Fit and Viability (Tjan, 2000) adoption. Together, these two dimensions form a simple matrix.

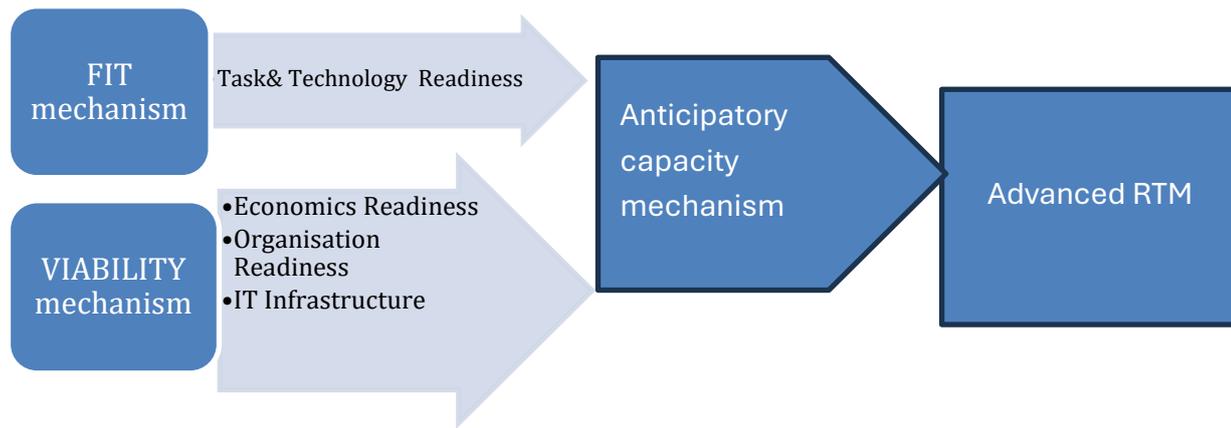


Fig. 5. A framework for adopting BCT for adaptive Radiation Therapy Systems

The formulated framework underpinned by the Fit and Viability theory, as shown in Figure 5, illustrates the readiness constructs. Fit is measured by matching the characteristics of task, anticipatory capacity and technology. Viability is measured by the economic, IT infrastructure and organization readiness of the project. The *FIT* dimension measures how well the blockchain's capabilities align with the requirements of the task it is intended to support. The possible capabilities are defined in Figure 3 (BCT innovative technological features). For a digitalised RTM, the various tasks include workflow requirements associated with the treatment planning, treatment delivery, and outcome evaluation. A good fit between a BCT enabled RTM system can lead to various benefits including improved patient empowerment & consent management, quality control & error reduction, secure immutable data management, data sharing & streamlined interoperability, improved data integrity, increased efficiency, and reduced costs as previously discussed in the last section. From this perspective of this study, BCT fitness refers to how well its unique characteristics and capabilities align with the RTM organization's specific needs and requirements.

The *VIABILITY* dimension assesses the organizational environment's readiness and ability to support the blockchain technology's long-term success. This includes economic feasibility, infrastructure maturity, and organizational support (top management support, user competence, business process impact). The dimension basically examines whether the RTM organization has the resources and capabilities necessary for successful adoption. By addressing both alignment and feasibility, the model helps organizations predict potential risks and make informed decisions. Viability is affected by the "RTM organization's infrastructure readiness for implementation" (Queiroz et al., 2021; Stafford & Treiblmaier, 2020). The infrastructure readiness involves evaluating the existing support infrastructure, technical expertise, and processes required to integrate the blockchain technology successfully. According Dhagarra, collaboration with sectors such as telecommunications and cloud solution providers also enhances blockchain solution-related infrastructure (Dhagarra et al., 2019). The viability also examines whether the BCT enabled adaptive RTM benefits (cost-effectiveness, efficiency gains) outweigh the costs associated with deployment and maintenance; and ask the questions of whether the RTM organization has the resources and capabilities necessary for successful adoption. The RTM organisation's readiness is an important influencing factor because it relies on interoperability and stakeholder collaboration to maximize its benefits. The ability of all "stakeholders to collaborate and use the system effectively" is a crucial issue to assess. In addition, "overcoming resistance to change and having an organizational culture that is open

to innovation is vital for transitioning to a decentralized blockchain system". It is not feasible for an individual RTM provider to unilaterally deploy BCT if it lacks the necessary technical and financial resources (Kulkarni & Patil, 2020). Thus, an RTM provider's capability to embrace and integrate BCT is "encompassed by organizational readiness". In the context of this study, organisation readiness refers to an organization's preparedness to undertake new initiatives or changes, while stakeholder readiness is the state of being prepared for the BCT project, determined by their awareness, willingness, and ability to adapt. Assessment of stakeholder's attitudes and capabilities of stakeholders are important concepts for new technology adoption and acceptance (Wondirad et al., 2020; Panagiopoulou & Skoultzos, 2025). Savage et al (2010) explains that when a blockchain project is implemented, the stakeholders' readiness, i.e., their availability and capacity of adopting a new technology, is important; and it is important in all its four dimensions: motivational, engagement, technological and structural (Balasubramanian et al., 2021; Li et al., 2012). The achievement level of each of the above different dimensions of readiness is an important element that impacts the blockchain implementation (Balasubramanian et al., 2021)

Empirical studies (e.g., Selvamuthu et al., 2025; Wazhi et al., 2024; Olukayode et al., 2023) on the BCT enabled healthcare digital transformation difficulties in low resources countries such as Nigeria found out that commitment from senior executives is crucial for providing necessary resources and direction for implementation. Top management support has a direct and significant impact on the viability of new technology adoption. According to Clohessy & Acton (2019), leaders who actively support and allocate resources toward technology adoption create an environment conducive to successful implementation, increasing the perceived viability of the technology. The radiotherapy experts involved in the study agrees that the involvement of RTM professionals such as radiologist in the development of health information system development, understanding of the technology, knowledge on how to use it, availability of skilled personnel, availability of supportive technical components, understanding of the risk, availability of sufficient funding, policies and regulatory frameworks in place are a must have for the success of any such BCT implementation. The e-Delphi experts also emphasize on the need for clarity on blockchain regulations and laws, and issues pertaining to privacy of patient data. The participants agrees that the proposed platform or system requires a trust layer built on top of the technical infrastructure, where users trust the platform, the consensus mechanism, and their peers.

The third dimension in the model is *ANTICIPATORY CAPACITY*. Anticipatory capacity is well described in (Rhodes & Ross, 2009; Amaechi, Kim, & Armand, 2024). Responsible innovative RTM organisation requires a capacity to change shape or direction in response to stakeholder and changing circumstances. Thus, anticipatory capacity is a must measure in any adaptive RTM setting. This is an assessment of the "capacity of the RTM organization to continuously develop and apply knowledge acquired through a structured approach to anticipate changing treatment scenarios as needs and context change over time". The RTM organisation must maintain the "ability to look forward in order to take a future decision and action, or the visualization of a future event or state". Anticipatory capacity extends from three key elements: competencies, methods, and a model-based environment. Fostering a culture of continuous learning and adaptation is a formidable means of enhancing the RTM anticipatory anticipation challenges.

5. Conclusion

Radiotherapy is only as good as the kit and the people. There are significant deficiencies in the availability of all components of radiotherapy in Nigeria as well as in most of the low resource countries. Literature and industrial experience show that the critical issues in traditional radiation oncology centres around data fragmentation, security vulnerabilities, slow information exchange, access-control policy enforcement and poor funding. One principle of BCT that provides an advantage in the field of radiotherapy is having a decentralised record such that patient information is securely stored and can be accessed across multiple health networks. In addition, updating or altering records is performed in an iterative manner that preserves a record of each change made. BCT is dynamic and capable of revolutionizing multiple aspects of radiotherapy practice and management by offering unprecedented transparency, immutability, security, and efficiency. Different authors have reported that the functionalities of BCT are continuously expanding due to its inherent decentralization, lack of reliance on trust, unchangeable storage, and ability to share information anonymously. Successful adoption of the proposed BCT-enabled radiotherapy framework requires a structured, multi-phase stakeholder engagement strategy to ensure operational alignment and real-world feasibility. Key stakeholder groups must be engaged through targeted efforts focused on awareness, capacity building, and collaborative governance.

References

1. Tumba Nuhu, Adeyemi Adewuyi Sunday, Eguzo Kelechi, Adenipekun Adeniyi, Oyeseun Rasaq (2020) Radiotherapy waiting time in Northern Nigeria: experience from a resource limited setting *ecancer* **14** 1097
2. Aruah SC, Chidebe RCW, Orjiakor TC, Uba F, Shagaya UN, Ugwanyi C, Umar AA, Ige T, Asogwa OC, Ahmadu OT, Ali-Gombe M, Adewumi A, Okwor VC, Mutiu JA, Bello B, Eriba LO, Ahmed YA, Bisalla A, Itanyi U, Balogun RA, Alabi S, Pistenmaa D, Coleman CN, Manjit D. Status of Government-Funded Radiotherapy Services in Nigeria. *JCO Glob Oncol.* 2023 Jun;9: e2200406. <https://doi.org/10.1200/GO.22.00406>.
3. Adewuyi, Sunday Adeyemi, Oladapo Babatunde Campbell, Kingsley Kayode Ketiku, Francis Abayomi Duronsinmi-Etti, Josbat Thomas Kofi-Duncan, and Philip Chinedu Okere. "Current status of radiation oncology facilities in Nigeria." *West African Journal of Radiology* 20, no. 1 (2013): 30-36. <https://doi.org/10.82235/wajr.vol20no1.232>
4. Mapoko BSE, Frambo A, Saidu Y, Mbassi EDB, Atenguena E, Azemafac K, Kobayashi E, Tabola L, Nkeng G, Sango A, Maison AM, Noa SA, Ntama A, Mapenya RRM, Tayou R, Kouya F, Mbah G, Douanla P, Fonkwa C, Biwole ME, Sando Z, Sone AM, Ndom P. Assessment of barriers to optimal cancer control in adult cancer treatment centres in Cameroon. *Ecancermedalscience.* 2023 Sep 21;17:1601. <https://doi.org/10.3332/ecancer.2023.1601>.
5. Mallum, A., Sibanda, W., et al., 2024. An Insight into the Current Status of the Radiotherapy Landscape in Africa: A Cross-sectional Survey Study on the Available Infrastructure and Human Resources. *Medical Research Archives*, [online] 12(11). <https://doi.org/10.18103/mra.v12i11.5749>
6. Zubizarreta E, Van Dyk J and Lievens Y (2017) Analysis of global radiotherapy needs and costs by geographic region and income level. *Clin Oncol (R Coll Radiol)* 29, 84–92.
7. Akinwande AM, Ugwuanyi DC, Chiegwu HU, Idigo F, Ogolodom MP, Anakwenze CP, Abi R, Odukoya O. Radiotherapy services in low resource settings: The situation in Nigeria. *SAGE Open Med.* 2023 Feb 7;11:20503121231153758. <https://doi.org/10.1177/20503121231153758>.
8. Ogunniyi TJ, Fatokun BS, Isah KO, Abdulkaki A, Emiola AR, Batisani K. Current Status of Cancer Diagnosis and Treatment in Nigeria. *Health Sci Rep.* 2025 May 29;8(6):e70877. doi: 10.1002/hsr2.70877.
9. Evbuomwan, M.O. et al. Psychosocial Factors Affecting Cancer Patients Undergoing Radiation Therapy in Lagos, Nigeria. *International Journal of Radiation Oncology, Biology, Physics*, Volume 120, Issue 2, e751 - e752
10. Connell, P.P.; Hellman, S. Advances in Radiotherapy and Implications for the Next Century: A Historical Perspective. *Cancer Res.* **2009**, 69, 383–392.
11. Huynh H, Hosny A, Guthier C, et al. Artificial intelligence in radiation oncology. *Nat Rev Clin Oncol.* 2020; 17: 771-781.
12. Bertholet, Jenny, Antje Knopf, Björn Eiben, Jamie McClelland, Alexander Grimwood, Emma Harris, Martin Menten et al. "Real-time intrafraction motion monitoring in external beam radiotherapy." *Physics in medicine & biology* 64, no. 15 (2019): 15TR01.
13. Chandra, Ravi A., Florence K. Keane, Francine EM Voncken, and Charles R. Thomas. "Contemporary radiotherapy: present and future." *The Lancet* 398, no. 10295 (2021): 171-184. [https://doi.org/10.1016/S0140-6736\(21\)00233-6](https://doi.org/10.1016/S0140-6736(21)00233-6).
14. Austin Amaechi & Steve Counsell, 2013. "Towards an Approach for a Conceptual System Design," *Systems Research and Behavioral Science*, Wiley Blackwell, vol. 30(6), pages 780-793,2013. <https://doi.org/10.1002/sres.2244>
15. Bhandari, A., Haynes, E., & Sulman, E. (2021). Addressing radiotherapy needs in low resource settings: The importance of logistics and planning. *Global Health Action*, 14(1), 1879790. <https://doi.org/10.1080/16549716.2021.1879790>
16. Kumar, S., Mehta, A., & Chaudhary, M. (2022). Technological advancements in radiotherapy: Bridging the gap in low-resource settings. *Clinical Oncology*, 34(5), e111-e118. <https://doi.org/10.1016/j.clon.2022.02.006>

17. Sikora, K., Ratanatharathorn, V., & Sweeney, C. (2020). Cancer treatment in low-income countries: A call for action. *The Lancet Oncology*, 21(3), e117-e121. [https://doi.org/10.1016/S1470-2045\(19\)30607-0](https://doi.org/10.1016/S1470-2045(19)30607-0)
18. Kenamond, Mark C., Waleed F. Mourad, Marcus E. Randall, and Aradhana Kaushal. "No oncology patient left behind: Challenges and solutions in rural radiation oncology." *The Lancet Regional Health—Americas* 13 (2022). <https://doi.org/10.1016/j.lana.2022.100289>
19. Kalidindi, Hari Krishna, and N. Srinivasu. "Deep Ensemble Model with Blockchain Technology for Lung Cancer Detection with Secured Data Sharing." *Computational Biology and Chemistry* (2025): 108729. <https://doi.org/10.1016/j.compbiolchem.2025.108729>.
20. Akintunde TY, Akintunde OD, Musa TH, et al. Expanding telemedicine to reduce the burden on the healthcare systems and poverty in Africa for a post-coronavirus disease 2019 (COVID-19) pandemic reformation. *Glob Health J.* 2021; 5(3):128–134. <https://doi.org/10.1016/j.glohj.2021.07.006>.
21. Jaffray, D. A., McKenzie, E., & Tan, K. (2021). Collaborations in global health: Building capacity for radiotherapy in low- and middle-income countries. *Cancer Journal*, 27(2), 92-99. <https://doi.org/10.1097/PPO.0000000000000589>
22. Alexander, Alan, Megan McGill, Anna Tarasova, Cara Ferreira, and Delphine Zurkiya. "Scanning the future of medical imaging." *Journal of the American College of Radiology* 16, no. 4 (2019): 501-507, <https://doi.org/10.1016/j.jacr.2018.09.050>.
23. Aithal, P. S., Architha Aithal, and Edwin Dias. "Blockchain technology-current status and future research opportunities in various areas of healthcare industry." *International Journal of Health Sciences and Pharmacy (IJHSP)* 5, no. 1 (2021): 130-150, <https://doi.org/10.47992/IJHSP.2581.6411.0070>.
24. McBee, Morgan P., and Chad Wilcox. "Blockchain technology: principles and applications in medical imaging." *Journal of digital imaging* 33, no. 3 (2020): 726-734, <https://doi.org/10.1007/s10278-019-00310-3>.
25. Bercovich, Eyal, and Marcia C. Javitt. "Medical imaging: from roentgen to the digital revolution, and beyond." *Rambam Maimonides medical journal* 9, no. 4 (2018): e0034, <https://doi.org/10.5041/RMMJ.10355>.
26. Ghadi, Y.Y., Mazhar, T., Shahzad, T. *et al.* The role of blockchain to secure internet of medical things. *Sci Rep* 14, 18422 (2024). <https://doi.org/10.1038/s41598-024-68529-x>
27. Strauss, A.L. *Qualitative Analysis for Social Scientists: Questions and Answers*; Cambridge University Press: Cambridge, MA, USA, 1987.
28. Glaser, B, Strauss, A. *Discovery of Grounded Theory: Strategies for Qualitative Research* (1st ed.), Routledge, New York (2017).
29. S. Jünger, S.A. Payne, J. Brine, L. Radbruch, S.G. Brearley. Guidance on Conducting and REporting DELphi Studies (CREDES) in palliative care: Recommendations based on a methodological systematic review. *Palliat Med*, 31 (2017 Sep 1), pp. 684-706
30. S. Keeney, H.A. McKenna, F. Hasson. *The Delphi technique in nursing and health research*. John Wiley & Sons (2011).
31. Niederberger M and Spranger J (2020) Delphi Technique in Health Sciences: A Map. *Front. Public Health* 8:457. <https://doi.org/10.3389/fpubh.2020.00457>
32. Kuo TT, Kim HE, Ohno-Machado L. Blockchain distributed ledger technologies for biomedical and health care applications. *J Am Med Inform Assoc.* 2017;24(6):1211–20. 10.1093/jamia/ocx068
33. Arksey, H.; O'malley, L. Scoping studies: Towards a methodological framework. *Int. J. Soc. Res. Methodol.* 2005, 8, 19–32.
34. Alabdulwahhab, Faten Adel. "Web 3.0: the decentralized web blockchain networks and protocol innovation." In 2018 1st International Conference on Computer Applications & Information Security (ICCAIS), pp. 1-4. IEEE, 2018.
35. Rathee, Geetanjali, Ashutosh Sharma, Rajiv Kumar, and Razi Iqbal. "A secure communicating things network framework for industrial IoT using blockchain technology." *Ad Hoc Networks* 94 (2019): 101933.
36. Zhao, Zhuoli, Juntao Guo, Xi Luo, Jizhong Xue, Chun Sing Lai, Zhirong Xu, and Loi Lei Lai. "Energy transaction for multi-microgrids and internal microgrid based on blockchain." *IEEE Access* 8 (2020): 144362-144372.

37. Zarrin, Javad, Hao Wen Phang, Lakshmi Babu Saheer, and Bahram Zarrin. "Blockchain for decentralization of internet: prospects, trends, and challenges." *Cluster Computing* 24, no. 4 (2021): 2841-2866. <https://doi.org/10.1007/s10586-021-03301-8>.
38. Bai, Chunguang, and Joseph Sarkis. "A supply chain transparency and sustainability technology appraisal model for blockchain technology." *International journal of production research* 58, no. 7 (2020): 2142-2162. <https://doi.org/10.1080/00207543.2019.1708989>.
39. Bai, Chunguang April, Joseph Sarkis, and Weili Xue. "Improving operational efficiency and effectiveness through blockchain technology." *Production Planning & Control* 35, no. 9 (2024): 857-865. <https://doi.org/10.1080/09537287.2024.2329182>
40. Dharmendra Hariyani, Poonam Hariyani, Sanjeev Mishra, Milind Kumar Sharma A literature review on transformative impacts of blockchain technology on manufacturing management and industrial engineering practices. *Green Technologies and Sustainability*. Volume 3, Issue 3, July 2025, 100169 <https://doi.org/10.1016/j.grets.2025.100169>
41. Crosby, Michael, P. Pattanayak, Sanjeev Verma, and Vignesh Kalyanaraman. "Applied innovation review." *Applied Innovation Review* 2 (2016): 5-20. Available at: <https://scet.berkeley.edu/wp-content/uploads/AIR-2016-Blockchain.pdf>
42. Narendra Kumar, Krishna Kumar, Anurag Aeron, Filippo Verre, Blockchain technology in supply chain management: Innovations, applications, and challenges, *Telematics and Informatics Reports*, Volume 18, 2025, 100204, <https://doi.org/10.1016/j.teler.2025.100204>.
43. Jamil F, Hang L, Kim K, Kim D. A novel medical blockchain model for drug supply chain integrity management in a smart hospital. *Electronics* 2019; 8: 505
44. Haleem A, Javaid M, Singh RP, Suman R, Rab S. Blockchain technology applications in healthcare: An overview. *Int J Intell Netw* 2021; 2: 130–139
45. Garriga, Martin, Stefano Dalla Palma, Maxmiliano Arias, Alan De Renzis, Remo Pareschi, and Damian Andrew Tamburri. "Blockchain and cryptocurrencies: A classification and comparison of architecture drivers." *Concurrency and Computation: Practice and Experience* 33, no. 8 (2021): e5992. <https://doi.org/10.1002/cpe.5992>
46. Nsowah, Nana-Yao, Kwame Assa-Agyei, Frederick Edem Junior Broni, Selina Amoah, and Daniel OT Ihenacho. "Blockchain Technology Readiness in Engineering Project Management: Industry Experts' Perspectives." In *World Congress in Computer Science, Computer Engineering & Applied Computing*, pp. 200-220. Cham: Springer Nature Switzerland, 2024. https://doi.org/10.1007/978-3-031-86637-1_15
47. Ghorashi N S, Rahimi M, Sirous R, Javan R (October 13, 2023) The Intersection of Radiology With Blockchain and Smart Contracts: A Perspective. *Cureus* 15(10): e46941. doi:10.7759/cureus.46941
48. Ghosh, P. K., Chakraborty, A., Hasan, M., Rashid, K. & Siddique, A. H. Blockchain application in healthcare systems: A review. *Systems* 11(1), 38 (2023)
49. Fraga-Lamas, P.; Fernández-Caramés, T.M.; Rosado Da Cruz, A.M.; Lopes, S.I. An Overview of Blockchain for Industry 5.0: Towards Human-Centric, Sustainable and Resilient Applications. *IEEE Access* 2024, 12, 116162–116201.
50. Xi, Peng, Xinglong Zhang, Lian Wang, Wenjuan Liu, and Shaoliang Peng. "A review of Blockchain-based secure sharing of healthcare data." *Applied Sciences* 12, no. 15 (2022): 7912.
51. Jian Zhu, Jinming Yu. Blockchain + Radiotherapy: The Scenarios of the 5G-Enabled Smart Radiotherapy Era. *Precision Radiation Oncology*. Volume7, Issue4. December 2023. Pages 268-272. <https://doi.org/10.1002/pro6.1211>
52. Tagliafico, Alberto Stefano, Cristina Campi, Bignotti Bianca, Chandra Bortolotto, Duccio Buccicardi, Coppola Francesca, Roberto Prost, Marco Rengo, and Lorenzo Faggioni. "Blockchain in radiology research and clinical practice: Current trends and future directions." *La radiologia medica* 127, no. 4 (2022): 391-397. <https://doi.org/10.1007/s11547-022-01460-1>.
53. Tomihama, Roger T., Michael C. Wilkinson, and Sharon C. Kiang. "Blockchain Technology: Overview and Applications in Radiology." *American Journal of Roentgenology* (2025).

54. Tadepalli, Kalyan, and Amar Ratnakar Naik. "BLOCKCHAIN-ENABLED RADIOLOGY: Transformative Potentials and Implementation Hurdles." In *Using Blockchain Technology in Healthcare Settings*, pp. 88-129. CRC Press, 2025.
55. Myeong, Go Eun, and Kim Sa Ram. "Blockchain Based Zero Knowledge Proof Protocol For Privacy Preserving Healthcare Data Sharing." *Journal of Technology Informatics and Engineering* 4, no. 1 (2025): 171-189.
56. Nezameslami A, Shahbazi A, Nezameslami R, Rashnavadi H, Pourkazemi M, Jayervand F, Akhondzardaini R, Rahmani A, Danaie M, Soleymani S, Yeganegi M, Aghili K, Neamatzadeh H. Enhancing Cancer Care through Blockchain Technology. *Asian Pac J Cancer Prev.* 2025 Apr 1;26(4):1139-1153. doi: 10.31557/APJCP.2025.26.4.1139.
57. Singh, Aditi P., Erin P. Balogh, Robert W. Carlson, Mary Margaret Huizinga, Bradley A. Malin, Alexander Melamed, Neal J. Meropol et al. "Re-envisioning electronic health records to optimize patient-centered cancer care, quality, surveillance, and research." *JCO Oncology Practice* 21, no. 2 (2025): 128-135. doi: <https://doi.org/10.1200/OP.24.00260>.
58. Othman, Soufiane Ben, and Masresha Getahun. "Leveraging blockchain and IoMT for secure and interoperable electronic health records." *Scientific Reports* 15, no. 1 (2025): 12358. <https://doi.org/10.1038/s41598-025-95531-8>.
59. Bhasker, B., P. Muralidhara Rao, P. Saraswathi, S. Gopal Krishna Patro, Javed Khan Bhutto, Saiful Islam, Mohammed Kareemullah, and Addisu Frinjo Emma. "Blockchain framework with IoT device using federated learning for sustainable healthcare systems." *Scientific Reports* 15, no. 1 (2025): 26736. <https://doi.org/10.1038/s41598-025-06539-z>.
60. Omar, Ilhaam A., Haya R. Hasan, Walaa AlKhader, Raja Jayaraman, Khaled Salah, and Mohammed Omar. "Blockchain-based trusted accountability in the maintenance of medical imaging equipment." *Expert Systems with Applications* 241 (2024): 122718.
61. Dubovitskaya, Alevtina, Furqan Baig, Zhigang Xu, Rohit Shukla, Pratik Sushil Zambani, Arun Swaminathan, Md Majid Jahangir et al. "ACTION-EHR: Patient-centric blockchain-based electronic health record data management for cancer care." *Journal of medical Internet research* 22, no. 8 (2020): e13598. <https://doi.org/10.2196/13598>.
62. Kamau, Gabriel, Caroline Boore, Elizaphan Maina, and Stephen Njenga. "Blockchain technology: Is this the solution to emr interoperability and security issues in developing countries?." In *2018 IST-Africa Week Conference (IST-Africa)*, pp. Page-1. IEEE, 2018.
63. Azogu, Irene, Alex Nort, Ingrid Papper, Justin Longo, and Dirk Draheim. "A framework for the adoption of blockchain technology in healthcare information management systems: A case study of Nigeria." In *Proceedings of the 12th International Conference on Theory and Practice of Electronic Governance*, pp. 310-316. 2019. <https://doi.org/10.1145/3326365.3326405>
64. Watat, Josue Kuika, Ebenezer Agbozo, and Rania El-Gazzar. "Blockchain technology in healthcare within the global south: mapping the area and developing a research scenario." *African Journal of Science, Technology, Innovation and Development* (2025): 1-18. <https://doi.org/10.1080/20421338.2025.2543235>
65. Patel, Vishal. "A framework for secure and decentralized sharing of medical imaging data via blockchain consensus." *Health informatics journal* 25, no. 4 (2019): 1398-1411. <https://doi.org/10.1177/1460458218769699>
66. Yeoh, Peter. "Regulatory issues in blockchain technology." *Journal of Financial Regulation and Compliance* 25, no. 2 (2017): 196-208. <https://doi.org/10.1108/JFRC-08-2016-0068>
67. Alzahrani, Saeed, Tugrul Daim, and Kim-Kwang Raymond Choo. "Assessment of the blockchain technology adoption for the management of the electronic health record systems." *IEEE Transactions on Engineering Management* 70, no. 8 (2022): 2846-2863. <https://doi.org/10.1109/TEM.2022.3158185>
68. Takashima, Kyoko, Yuichi Maru, Seiichi Mori, Hiroyuki Mano, Tetsuo Noda, and Kaori Muto. "Ethical concerns on sharing genomic data including patients' family members." *BMC medical ethics* 19, no. 1 (2018): 61. <https://doi.org/10.1186/s12910-018-0310-5>
69. Shuaib, Khaled Heba Saleous, Karim Shuaib, and Nazar Zaki. "Blockchains for secure digitized medicine." *Journal of personalized medicine* 9, no. 3 (2019): 35.

70. Maesa, Damiano Di Francesco, and Paolo Mori. "Blockchain 3.0 applications survey." *Journal of Parallel and Distributed Computing* 138 (2020): 99-114.
71. Khan, Dodo, Low Tang Jung, and Manzoor Ahmed Hashmani. "Systematic literature review of challenges in blockchain scalability." *Applied Sciences* 11, no. 20 (2021): 9372. <https://doi.org/10.3390/app11209372>
72. Khan, Shahbaz, Abid Haleem, Zafar Husain, Daniel Samson, and Raghuvar D. Pathak. "Barriers to blockchain technology adoption in supply chains: the case of India." *Operations Management Research* 16, no. 2 (2023): 668-683, <https://doi.org/10.1007/s12063-023-00358-z>
73. Kim, Soohyeong, Yongseok Kwon, and Sunghyun Cho. "A survey of scalability solutions on blockchain." In *2018 International Conference on Information and Communication Technology Convergence (ICTC)*, pp. 1204-1207. IEEE, 2018, <https://doi.org/10.1109/ICTC.2018.8539529>
74. Kasyapa MSB, Vanmathi C. Blockchain integration in healthcare: a comprehensive investigation of use cases, performance issues, and mitigation strategies. *Front Digit Health* 2024; 6:1359858
75. Bada, Abigael Okikijesu, Amalia Damianou, Constantinos Marios Angelopoulos, and Vasilios Katos. "Towards a green blockchain: A review of consensus mechanisms and their energy consumption." In *2021 17th international conference on distributed computing in sensor systems (DCOSS)*, pp. 503-511. IEEE, 2021. <https://doi.org/10.1109/DCOSS52077.2021.00083>.
76. Wenhua, Zhang, Faizan Qamar, Taj-Aldeen Naser Abdali, Rosilah Hassan, Syed Talib Abbas Jafri, and Quang Ngoc Nguyen. "Blockchain technology: security issues, healthcare applications, challenges and future trends." *Electronics* 12, no. 3 (2023): 546. [10.3390/electronics12030546](https://doi.org/10.3390/electronics12030546)
77. Asif, Rameez, and Syed Raheel Hassan. "Shaping the future of Ethereum: Exploring energy consumption in Proof-of-Work and Proof-of-Stake consensus." *Frontiers in Blockchain* 6 (2023): 1151724. [10.3389/fbloc.2023.1151724](https://doi.org/10.3389/fbloc.2023.1151724)
78. Mohanta, Bhabendu Kumar, Soumyashree S. Panda, and Debasish Jena. "An overview of smart contract and use cases in blockchain technology." In *2018 9th international conference on computing, communication and networking technologies (ICCCNT)*, pp. 1-4. IEEE, 2018. <https://doi.org/10.1109/ICCCNT.2018.8494045>
79. Bazel, Mahmood A., Fathey Mohammed, Mazida Ahmad, Abdullah O. Baarimah, and Tahra Al Maskari. "Blockchain technology adoption in healthcare: an integrated model." *Scientific Reports* 15, no. 1 (2025): 14111. <https://doi.org/10.1038/s41598-025-95253-x>
80. Abdul-Moheeth, Mustafa, Muhammad Usman, Daniel Toshio Harrell, and Anjum Khurshid. "Improving transitions of care: designing a blockchain application for patient identity management." *Blockchain in healthcare today* 5 (2022): 10-30953. <https://doi.org/10.30953/bhty.v5.200>.
81. Anthony Jnr, Bokolo. "Enhancing blockchain interoperability and intraoperability capabilities in collaborative enterprise-a standardized architecture perspective." *Enterprise Information Systems* 18, no. 3 (2024): 2296647. <https://doi.org/10.1080/17517575.2023.2296647>
82. Alzahrani, Abdulrahman, Amin Noaman, Ahmed AA Gad-Elrab, Fathy Eassa, Maher Khemakhem, Faisal Albalwy, and Hosam Aljihani. "Design and implementation of a decentralized trustless data standardization framework for blockchain interoperability using smart contracts." *Alexandria Engineering Journal* 129 (2025): 168-191, <https://doi.org/10.1016/j.aej.2025.06.011>.
83. Wazhi, Godsave Binlak, Nengak Precious Danladi, Sesugh Daniel Terver, and Stephen Ebuka Ukaobasi. "Blockchain technology in healthcare strengthening: The Nigerian case." *BioSocial Health journal* 1, no. 4 (2024): 173-178. <https://doi.org/10.34172/bshj.37>
84. Chang, Shuchih Ernest, Yi-Chian Chen, and Ming-Fang Lu. "Supply chain re-engineering using blockchain technology: A case of smart contract-based tracking process." *Technological forecasting and social change* 144 (2019): 1-11.
85. Ruoti, Scott, Ben Kaiser, Arkady Yerukhimovich, Jeremy Clark, and Robert Cunningham. 2020. Blockchain Technology: What Is It Good For? *Communications of ACM* 63: 46–53
86. Taherdoost, H.; Masrom, M. An examination of smart card technology acceptance using adoption model. In *Proceedings of the ITI 2009 31st International Conference on Information Technology Interfaces*, Cavtat, Croatia, 22–25 June 2009; pp. 329–334.

87. Taherdoost, H. "A Critical Review of Blockchain Acceptance Models—Blockchain Technology Adoption Frameworks and Applications," *Computers*, vol. 11, no. 2, Feb. 2022, Art. no. 24. <https://doi.org/10.3390/computers11020024>.
88. Taherdoost, H.; Madanchian, M. *Developing and Validating a Theoretical Model to Evaluate Customer Satisfaction of E-Services*; IGI Global: Hershey, PA, USA, 2020; pp. 46–65.
89. Tjan, Anthony K. "Finally, a way to put your Internet portfolio in order." *Harvard business review* 79, no. 2 (2001): 76-85.
90. Queiroz, M. M., Wamba, F. S., De Bourmont, M. & Telles, R. Blockchain adoption in operations and supply chain management: empirical evidence from an emerging economy. *Int. J. Prod. Res.* **59** (20), 6087–6103. <https://doi.org/10.1080/00207543.2020.1803511> (2021).
91. Stafford, T. F. & Treiblmaier, H. Characteristics of a blockchain ecosystem for secure and sharable electronic medical records. *IEEE Trans. Eng. Manag.* **67** (4), 1340–1362. <https://doi.org/10.1109/TEM.2020.2973095> (2020).
92. Dhagarra D., Goswami M., Sarma P.R.S., Choudhury A. *Big Data and blockchain supported conceptual model for enhanced healthcare coverage: The Indian context. Business Process Management Journal.* 2019;25(7):1612–1632.
93. Kulkarni, M. & Patil, K. Block chain technology adoption using toe framework. *Int. J. Sci. Technol. Res.* **9** (2), 1109–1117 (2020).
94. Wondirad, Amare, Denis Tolkach, and Brian King. "Stakeholder collaboration as a major factor for sustainable ecotourism development in developing countries." *Tourism management* 78 (2020): 104024.
95. Panagiotopoulou, Polymnia, and Sofoklis Skoultzos. "Stakeholders' Involvement in Sustainable Destination Management: A Systematic Literature Review of Existing Multi-Stakeholder Frameworks and Approaches." *Tourism and Hospitality* 6, no. 5 (2025): 250. <https://doi.org/10.3390/tourhosp6050250>
96. Savage, G. T., Bunn, M. D., Gray, B., Xiao, Q., Wang, S., Wilson, E. J., & Williams, E. S. (2010). Stakeholder Collaboration: Implications for Stakeholder Theory and Practice. *Journal of Business Ethics*, 96(S1), 21–26. <https://doi.org/10.1007/s10551-011-0939-1>
97. Balasubramanian, S., Shukla, V., Sethi, J. S., Islam, N., & Saloum, R. (2021). A readiness assessment framework for Blockchain adoption: A healthcare case study. *Technological Forecasting and Social Change*, 165, 120536. <https://doi.org/10.1016/j.techfore.2020.120536>
98. Li, J., Ray, P., Seale, H., MacIntyre, R., (2012). An E-Health readiness assessment framework for public health services—Pandemic perspective. In *Proceedings of 45th Hawaii International Conference on System Sciences*, IEEE, pp. 2800–2809. doi:10.1109/HICSS.2012.95.
99. Selvamuthu, C. M., M. Salwin, D. Akshitha, Shaan D. Jain, V. K. Kavya, O. Manoj Kumar, and Vidur Karwa. "Transforming Healthcare with Blockchain: A Study on its Applications, Benefits and Barriers." *Journal of Pioneering Medical Sciences* 14, no. 6 (2025).
100. Olukayode, AYEPEKU F., OMOSOLA J. Olabode, EZEKIEL K. Olatunji, ROTIMI O. Folaranmi, SAMUEL O. Olofinlade, and AYENI J. Kehinde. "Blockchain Technology and Record-Keeping in the Nigerian Healthcare System: A Systematic Review." *University of Pitesti Scientific Bulletin Series: Electronics and Computer Science* 23, no. 2 (2023): 13-20.
101. Rhodes, Donna H., and Adam M. Ross. "Anticipatory capacity: Leveraging model-based approaches to design systems for dynamic futures." In *2009 International Conference on Model-Based Systems Engineering*, pp. 46-51. IEEE, 2009
102. Amaechi, A. O., Kim, H. C., & Armand, T. P. T. (2024). Phenomenological Examination of Project Delivery Leaders Navigation of Project Complexity. *Open Access Library Journal*, 11(6), 1-27.
103. Clohessy, T. & Acton, T. Investigating the influence of organizational factors on blockchain adoption: an innovation theory perspective. *Industrial Manage. Data Syst.* 119, 1457–1491. <https://doi.org/10.1108/IMDS-08-2018-0365> (2019).