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Review Article

Unblocking Innovation: A Meta-Synthesis of Blockchain Applications in Medical Education, Research, and Healthcare

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Abstract

Background: In today's digital era, challenges related to privacy, security, and transparency in the management of sensitive medical data continue to impede progress in healthcare innovation. Blockchain technology, with its decentralized and tamper-resistant architecture, presents a promising avenue to address these issues. However, a comprehensive meta-synthesis examining blockchain applications across medical education, research, and healthcare delivery remains lacking.

Objectives: The purpose of this study is to investigate and identify the applications of blockchain technology within the domains of medical education, medical research, and healthcare.

Methods: The current study utilized a meta-synthesis methodology to analyze 49 peer-reviewed articles published between 2008 and 2025. Sources were identified through systematic searches of reputable academic databases and selected based on defined inclusion and exclusion criteria aligned with PRISMA guidelines. Relevant data were extracted, coded, categorized, and synthesized into overarching thematic domains.

Results: Findings revealed that blockchain enhances medical education by improving the issuance and verification of academic credentials, enabling adaptive learning, supporting competency-based assessments, and promoting interactive, learner-centered environments. In the domain of medical research, blockchain contributes to secure data sharing, improved research ethics, enhanced transparency, and more effective inter-institutional collaboration. In healthcare delivery, the technology enables secure and interoperable health record management, pharmaceutical supply chain monitoring, privacy-preserving telemedicine, and intelligent clinical decision-making. Overall, these applications were categorized into six thematic categories for education, eight for research, and nine for healthcare.

Conclusion: Blockchain technology, by offering a secure, transparent, and decentralized infrastructure, holds significant potential to transform medical education, research, and healthcare delivery. The findings of this meta-synthesis provide a conceptual framework for the optimal integration of blockchain within the healthcare system and illuminate pathways for future research aimed at advancing the practical applications of this technology.

Keywords: Blockchain; Medical Education; Medical Research; Health Care; Technology Assessment

Background

Access to accurate and comprehensive medical data is fundamental to the effective delivery of healthcare services. Yet, the digital era presents a paradox: while vast amounts of patient information are now digitally stored in electronic health records (EHRs) and medical devices, this enhanced accessibility concurrently exposes significant vulnerabilities in data privacy and security. Traditional centralized data repositories are prone to cyberattacks, human error, and a lack of transparency, thereby raising concerns about trustworthiness and potential misuse of sensitive medical information (1). Furthermore, medical data often remain siloed within individual institutions, impeding timely clinical decision-making and limiting opportunities for cross-institutional research collaboration. To address these challenges, blockchain technology has emerged as a promising decentralized infrastructure that offers tamper-resistant data management. The intrinsic cryptographic techniques and distributed network architecture of blockchain technology provide robust protection against unauthorized access and data manipulation, especially in handling large-scale healthcare datasets (2). Structurally, blockchain can be defined as a sequential ledger comprising interconnected blocks (3). Each block consists of a header and a body with the body containing transactional data while the header including a cryptographic hash of the preceding block, thereby ensuring the immutability and chronological integrity of the chain (4). Since the latter half of 2017, blockchain has garnered increasing attention from key stakeholders in the healthcare sector (5), with forecasts predicting substantial growth in applications such as EHR management, insurance claims processing, biomedical research, pharmaceutical supply chain oversight, and medical education (6-7). Stagnaro (8) highlights five critical applications of blockchain capable of mitigating persistent healthcare challenges, incuding creation of longitudinal health records, automated insurance claims, interoperability among heterogeneous systems, patient-controlled data access, and secure pharmaceutical supply chain management. Despite its transformative potential in enhancing data integrity, transparency, and decentralized trust, blockchain adoption faces multifaceted challenges including ethical considerations (9), unintended reinforcement of power asymmetries via smart contracts (10), lack of standardized protocols (11), privacy concerns (12), legal ambiguities regarding digital asset ownership (13), economic barriers related to infrastructure and energy consumption (14), and limited user acceptance due to technological literacy gaps (15). These complexities underscore the necessity for a multidisciplinary approach integrating ethical, legal, social, and technical perspectives to responsibly advance blockchain solutions in healthcare.

In contemporary healthcare, access to accurate, comprehensive, and timely medical data is essential for effective service delivery. The digital transformation has facilitated widespread adoption of electronic health records (EHRs) and medical devices, significantly increasing data availability. However, this advancement also introduces critical challenges related to data security and patient privacy. Centralized data systems remain vulnerable to cyberattacks, human errors, and transparency deficits, undermining trust in healthcare data management. Additionally, the fragmentation of medical information across multiple institutions restricts timely care delivery and impedes cross-institutional research collaboration. Despite the growing recognition of blockchain technology as a promising solution to these issues, there remains a significant research gap regarding its comprehensive applications in medical education, research, and healthcare services. Much of the existing literature addresses isolated aspects without offering an integrative, content-driven synthesis. Emerging evidence suggests blockchain's potential to enhance pharmaceutical supply chains, automate insurance claims, increase transparency in biomedical research, and improve patient access to records; however, these applications have yet to be examined holistically. To address this gap, the current study employed a meta-synthesis methodology to systematically analyze qualitative research on blockchain applications in medical fields. This interdisciplinary approach can facilitate the identification of conceptual gaps, thematic overlaps, and emerging trends, providing a unified framework to understand blockchain's multifaceted role, challenges, and future prospects in healthcare, education, and research.

Objectives

The purpose of this study is to investigate and identify the applications of blockchain technology within the domains of medical education, medical research, and healthcare.

Methods

The present study adopted a qualitative research design consistent with its objective, subject matter, and methodological approach. Specifically, it employed the meta-synthesis strategy, defined as a systematic integration and interpretation of findings from multiple studies within a particular domain, aimed at generating a deeper understanding of the phenomenon under investigation. This process involves four main stages: formulating research questions, applying a search strategy, extracting key concepts, and synthesizing those concepts (16).

Designing Research Questions

As the initial phase of the meta-synthesis mapping process, we formulated three core research questions aligned with our aim to explore and clarify the current advancements and trends in the utilization of blockchain technology within the domains of education, scientific research, and healthcare. The research questions addressed in this study were as follows:

1) What are the applications of blockchain in the field of medical education?
2) What are the applications of blockchain in the field of medical research?
3) What are the applications of blockchain in the field of healthcare?

Systematic Review Search Strategy

In the second phase involving the systematic mapping process, primary studies were selected by searching scientific databases using a search string and specific keywords.

Data Sources and Search Strategies

Studies published between 2008 to 2025 were included in the research. November 2008 was set as the starting point for the publications included in this systematic investigation, as it marks the introduction of blockchain technology by Satoshi Nakamoto. To gather a wide range of scholarly work, searches were carried out across multiple academic databases, including ACM Digital Library, Emerald, Google Scholar, IEEE, Science Direct, Springer, PubMed, Taylor & Francis Online, and Wiley Online Library. We used a carefully designed search strategy based on the keyword set outlined in Table 1 to identify relevant publications. Since search terms serve as the primary gateway for retrieving meaningful literature, their accurate selection was essential to ensure the relevance and quality of the included sources (17). The initial search yielded 274 records, among which 17 were identified as duplicates and removed. Therefore, the remaining 257 studies were reviewed according to the inclusion and exclusion criteria, resulting in the identification of a total of 49 studies fulfilling the eligibility requirements. The entire search and screening process adhered to the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework (18), as visually summarized in Figure 1.

Table 1 outlines a comprehensive keyword search strategy combining both broad and specific Boolean queries to capture the intersection of blockchain technology and its applications in medical education, healthcare innovation, and medical research.

Inclusion and Exclusion Criteria

The articles that met the inclusion and exclusion criteria (Table 2) were subjected to detailed analysis for the Meta-Synthesis research.

Quality Assessment

A quality evaluation was performed on the eligible studies (N = 49), using seven criteria derived from a structured assessment framework. As emphasized by Al-Emran et al. (19), evaluating the quality of studies is as critical as applying inclusion and exclusion standards. The assessment tool, illustrated in Table 3, was adapted from the recommendations of Kitchenham and Charters (20), with modifications tailored to the current study's context.

It is important to note that the checklist was not intended to criticize the work of any individual researcher.

A three-tier scoring system was used, assigning 1 point for "Yes," 0.5 for "Partially," and 0 for "No" responses. Each article could achieve a score ranging from 0 to 7 with a higher score reflecting a stronger capacity to effectively address the research questions. The quality assessment results for each article are shown in Table 3, confirming that all 49 studies fulfilled the quality standards and were deemed suitable for further in-depth analysis. Three independent researchers conducted the quality assessment separately, and any discrepancies were resolved through discussion and consensus.

Data Analysis

Data Extraction: The general characteristics of the included studies were extracted to provide a comprehensive understanding of the literature. Key information included author(s), country of origin, research objectives, methodologies, and main findings. Globally, researchers have extensively investigated the potential of blockchain in healthcare and medical education. Distinct regional emphases were observed: the United Kingdom and the United States concentrated on data security and smart contracts; India prioritized electronic health records (EHRs) and drug traceability; Pakistan explored credentialing and artificial intelligence (AI) integration; and China, Taiwan, and Singapore examined strategic technology models. In contrast, Canadian studies focused on interoperability and supply chain management. Additional research from other countries addressed governance, clinical trials, and applications in low-resource settings, collectively reflecting a global and multidisciplinary effort to advance blockchain adoption in healthcare.

Data Coding and Analysis: References (21–69) are provided in Table 2. An inductive, interpretive content analysis was conducted to analyze the qualitative data (70). Themes were derived directly from the raw text, without reliance on predefined theories. Relevant article sections were transcribed and repeatedly reviewed to ensure contextual understanding. The entire article functioned as the unit of analysis to maintain conceptual integrity. Text was segmented into condensed meaning Units, each assigned a representative code reflecting its core idea. Codes were then grouped into themes based on semantic similarity, conceptual coherence, contextual relevance, and frequency of occurrence. This approach ensured a nuanced, data-driven interpretation of the phenomenon under investigation.

Data Validation: To evaluate the consistency of the results, all identified conceptual elements were subjected to a reliability assessment. The procedure involved a single researcher conducting the categorization process on two separate occasions. By comparing the outcomes from both sessions, the degree of classification consistency was determined. Codes that remained the same across both rounds were marked as "matches," while differing codes were labeled as "non-matches." The frequency of matches and non-matches was then applied to a specific equation to calculate the overall stability of the coding process. In this study, the coding was repeated by the same researcher after a 20-day interval, yielding a total of 417 unique items, of which 201 were consistently categorized across both sessions. The resulting test–retest reliability was calculated at 96%, far exceeding the commonly accepted benchmark of 60%, thereby confirming the robustness and dependability of the coding procedure.

$$\text{Test-Retest Reliability} = 100 \times \left(\frac{201\times 2}{417}\right) = 96\%$$

Ethical Considerations: The authors have avoided plagiarism, faithfully cited original authors, and respected intellectual property throughout the review process. Additionally, the analysis was conducted with transparency and objectivity to maintain scholarly rigor.

Results

The content analysis of the selected studies led to the identification of the main themes related to the applications of blockchain technology in the fields of education, research, and healthcare. These conceptual themes were extracted based on the frequency of their occurrence in the reviewed studies and the relevance of the associated keywords. To illustrate the significance and level of focus on each theme, charts were employed to visually represent frequency distributions and facilitate comparisons across key concepts. The findings are presented in three separate summary tables (i.e., Tables 4-6).

Applications of blockchain in medical education: Table 4 presents the applications of blockchain in medical education, categorized into six main themes based on their underlying key concepts and grouped according to their conceptual similarities and differences. The frequency of each theme is also indicated to reflect its relative emphasis within the reviewed literature.

As summarized in Table 4, the results highlighted blockchain's key role in medical education, particularly in the secure management of academic records and the verification of credentials to enhance trust and transparency. The results were also indicative of the role of blockchain technology in supporting personalized learning through adaptive pathways and data analysis. Based on the reviewed literature, interactive platforms such as the metaverse encourage collaboration and immersive simulations, while continuous data-driven assessments enhance decision-making and professional development. Overall, blockchain optimizes educational processes, significantly enhancing the efficiency and quality of medical education systems.

As illustrated in Figure 2, 'Academic records management', with the highest frequency (n=15), represented the most prominent application of blockchain in education, while 'Learning in the metaverse environment', with the lowest frequency (n=8), received comparatively less attention among the identified themes.

Applications of blockchain in medical research: The applications of blockchain in the field of medical research are summarized in Table 5.

These applications are categorized into eight main themes, derived from their underlying key concepts. The frequency associated with each main theme is also provided to indicate the extent of emphasis within the analyzed literature.

The data analysis revealed blockchain's vital role in medical research by enhancing security, transparency, and efficiency. As indicated across the reviewed studies, the immutable infrastructure of this technology can safeguard data integrity and prevent manipulation, thereby fostering trust among stakeholders. The findings also demonstrated that blockchain promotes reliable interdisciplinary collaboration, research accountability, and ethical practices through permanent traceability. Additionally, it automates research processes by increasing productivity and supporting study design to data analysis. These features underscore blockchain's emerging importance as a key enabler of scientific innovation.

As displayed in Figure 3, 'Trust, accountability, and research ethics' and 'Automation and research efficiency' (n=14 each) emerged as the most frequently reported applications of blockchain in research. In contrast, 'Research data management' and 'Research governance' (n=8 each) were the least emphasized among the identified themes.

Applications of blockchain in the field of healthcare: Table 6 presents the key applications of blockchain in healthcare. These applications are categorized into nine main themes based on their underlying key concepts, with the corresponding frequency of each theme also being provided to indicate their relative emphasis in the reviewed literature.

The analysis of the literature highlighted blockchain's crucial role in healthcare by enhancing data security, transparency, and integrity.

The key applications identified include patient record management, pharmaceutical supply chain oversight, and data privacy. As indicated in the findings, blockchain also supports telemedicine, personalized care, and inter-institutional data exchange, driving digital transformation. Additionally, it improves efficiency by streamlining insurance and billing processes while reducing errors. Figure 4 illustrates the relative frequency of these key themes in the data.

As shown in Figure 4, 'Health data and records management" (n=63) and 'Pharmaceutical supply chain' (n=62) were found to be the most prominent applications of blockchain in the healthcare sector. In contrast, 'Continuous health monitoring and evaluation' (n=11) was the least discussed application.

Discussion

Artificial intelligence has revolutionized medicine, notably enhancing education and research. Among these advances, blockchain ensures data transparency, security, and immutability, fostering trust in digital transactions. By removing intermediaries, blockchain technology improves efficiency across sectors. This study systematically explores blockchain's applications in medical education, research, and healthcare.

Applications of blockchain medical education: Blockchain technology presents diverse and promising applications in medical education. By facilitating personalized learning pathways, blockchain enables students to tailor their educational journeys to their unique needs, interests, and career objectives. Blockchain technology can significantly enhance collaborative learning by providing a secure and transparent platform that fosters interaction and cooperation among students. Through decentralized data sharing, learners can actively engage in group tasks while maintaining shared responsibility and accountability for both individual and collective outcomes. Moreover, the immutability and transparency of blockchain records promote trust and reflection within the learning process, thereby strengthening the overall effectiveness of active and participatory learning (71). A key application of blockchain is the secure issuance, validation, and sharing of academic credentials. Digital certificates recorded on the blockchain are tamper-proof, mitigating risks of forgery and manipulation (72). Additionally, blockchain can maintain immutable, encrypted academic transcripts that document students' comprehensive educational records, such as grades, certifications, and honors, in a decentralized and transparent manner. This improves record security and simplifies administrative processes like verification and credential transfer (73). Blockchain also offers innovative solutions for learner assessment. In blockchain-enabled educational settings, students' performance data, covering grades, skill development, and group participation, can be securely and transparently stored. This is particularly valuable in collaborative learning, where peer assessments can be immutably recorded, ensuring fairness and reducing bias (74). While these applications highlight blockchain's transformative potential, challenges persist. High energy consumption, increasing confirmation times, and scalability issues pose significant barriers, especially given the large volumes of educational data processed by institutions (75). Addressing these challenges is critical for broader adoption in medical education. These insights align with the findings of the current study and are consistent with prior research on blockchain applications in medical education (21-23, 32, 33, 49, 51, 54).

Applications of blockchain in medical research: Blockchain technology has shown substantial potential in transforming medical research, particularly in clinical trials where data integrity, security, and transparency are paramount. As a decentralized and tamper-resistant infrastructure, blockchain enables secure, traceable, and efficient data sharing and storage, allowing all data interactions within clinical studies to be closely monitored (76). This immutability enhances the credibility of research findings, ensuring that clinical trial data remain accurate, verifiable, and resistant to manipulation (77). Furthermore, blockchain allows for decentralized storage of sensitive personal data with strict access controls, protecting participant privacy. Smart contracts can automate and enforce research protocols, ensuring consistent adherence to data collection and analysis procedures. This automation enhances transparency, regulatory compliance, and operational efficiency across the research pipeline (78). In addition to improving data integrity, blockchain helps address challenges related to data authenticity and validation, thereby increasing trust in scientific outputs and enabling more reliable drug development and policy decisions (79). These capabilities align with the findings of the current study and are supported by prior research (22-24, 26, 28, 32-34, 37-40, 43, 44, 47, 50, 51, 53, 55, 58-63, 67). However, the adoption of blockchain in medical research faces obstacles, particularly for researchers lacking technical expertise. The complexity of system design, implementation, and maintenance may hinder widespread integration (80).

Applications of blockchain in healthcare: Blockchain technology offers transformative potential within the healthcare sector by enabling secure, integrated, and interoperable management of patient data. Through decentralized and immutable data storage, blockchain ensures that medical records are tamper-proof and accessible only to authorized users, supporting the creation of unified health records updated in real time across providers (81). This enhances data sharing, streamlines access to records, and strengthens data privacy. In pharmaceutical supply chains, blockchain improves traceability and auditability through both on-chain and off-chain data management. Research has highlighted its role in fraud detection, EMR optimization, and privacy protection, particularly when integrated with emerging technologies like IoT (82). Blockchain also supports shared infrastructures between insurers and healthcare institutions, facilitating faster claims processing and real-time billing with increased transparency and accuracy (83). Furthermore, it secures healthcare communication systems, promoting trust and system interoperability (84). In personalized medicine, blockchain enables the secure storage of sensitive data, such as genomic and lifestyle information, supporting AI-driven, patient-specific treatment plans while preserving privacy (85). These insights align with a broad body of literature on blockchain in healthcare (24, 29-69).

Limitations: This meta-synthesis primarily relies on qualitative and conceptual literature, lacking quantitative and empirical data, which limits assessment of blockchain's real-world effectiveness. It does not consider country-specific legal, infrastructural, or cultural factors, restricting applicability across diverse healthcare contexts. Exclusion of gray literature and omission of regional or institutional variations further constrain generalizability, especially in low-resource or early-stage digital health environments.

Conclusion

The findings of this study suggest that blockchain technology, beyond being a mere technological tool, functions as a transformative infrastructure capable of playing a pivotal role in redefining healthcare systems. By leveraging core features, such as transparency, security, and decentralization, blockchain has the potential to drive meaningful change not only at the operational level but also in policy-making and system-wide strategic design. Accordingly, this article goes beyond merely identifying potential applications of blockchain; it proposes an analytical framework to guide future actions.

At the operational level, ministries of health and insurance organizations could utilize blockchain to establish national health record systems built around individual data ownership and secure interoperability. Academic institutions and medical education authorities may implement this technology to issue verifiable digital credentials and design adaptive, personalized learning pathways. In the research domain, scientific institutions and research ethics committees can deploy blockchain to structure the processes of data registration, review, and oversight in a transparent and accountable manner. Collectively, these proposals offer practical pathways for translating research insights into implementation and provide a strategic foundation for advancing national digital health initiatives.

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Ethical approval: The present manuscript is a meta-synthesis of previously published literature. Since it does not involve original research with human subjects or animals, no ethical approval was required.

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Table 1. Keyword search

Keyword search
Blockchain Technology AND Medical Education AND Healthcare Innovation AND Medical Research AND Blockchain Applications; Blockchain Technology OR Medical Education OR Healthcare Innovation OR Medical Research OR Blockchain Applications(Blockchain Technology AND Medical Education) OR (Blockchain Technology AND Medical Research) OR (Blockchain Technology AND Healthcare Innovation); (Blockchain Applications AND Medical Education) OR (Blockchain Applications AND Healthcare Innovation); (Blockchain Technology OR Blockchain Applications) AND (Medical Education OR Medical Research OR Healthcare Innovation)

Table 2. Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
Must involve blockchain systems in medical education, medical research, and healthcare, must involve research framework, must qualitative research, must be written in English language, must be published between 2008 and 2025	Articles on blockchain systems but not in medical field, Articles without research framework, Articles published in languages other than English

Table 3. Quality assessment results

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Total
(21)	Yes	Partially	Yes	Yes	Yes	Yes	Partially	6.0/7
(22)	Yes	Partially	Yes	Yes	Yes	Yes	Partially	6.0/7
(23)	Yes	Partially	Yes	Yes	Yes	Yes	Partially	6.0/7
(24)	Yes	No	Partially	Yes	Yes	Partially	Yes	5.0/7
(25)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(26)	Yes	No	Yes	Yes	Yes	Yes	Yes	6.0/7
(27)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(28)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(29)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(30)	Yes	Partially	Yes	Yes	Yes	Yes	Partially	6.0/7
(31)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(32)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(33)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(34)	Yes	Partially	Yes	Yes	Yes	Yes	Partially	7.0/7
(35)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(36)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(37)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(38)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(39)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(40)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(41)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(42)	Yes	Partially	Yes	Yes	Yes	Yes	Partially	6.0/7
(43)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(44)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(45)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(46)	Yes	Partially	Yes	Yes	Partially	Yes	Partially	5.5/7
(47)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(48)	Yes	Partially	Yes	Yes	Yes	Yes	Partially	6.0/7
(49)	Yes	Partially	Yes	Yes	Yes	Yes	Yes	6.5/7
(50)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(51)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(52)	Yes	Partially	Yes	Yes	Yes	Yes	Partially	6.0/7
(53)	Yes	Partially	Yes	Yes	Yes	Yes	Partially	6.0/7
(54)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(55)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(56)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(57)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7

(58)	Yes	Partially	Yes	Yes	Yes	Yes	Partially	6.0/7
(59)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(60)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(61)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(62)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(63)	Yes	Partially	Yes	Yes	Yes	Yes	Yes	6.5/7
(64)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(65)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(66)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(67)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(68)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7
(69)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	7.0/7

The quality of the included studies was evaluated based on a three-point scoring system, where each criterion was rated as 1 (Yes) if fully met, 0.5 (Partially) if partially met, and 0 (No) if not met at all. Studies scoring above 4 out of 7 were considered eligible for further analysis, while those scoring 4 or below were excluded due to insufficient methodological rigor or relevance.

Table 4. Blockchain applications in medical education

Main themes	Key concepts	Frequency
Secure, transparent, and efficient management of academic records.	Secure and transparent recording of academic information (21, 22, 32); Reliable credential verification (21, 23); Creation of immutable records for performance and certifications (21); A secure system for issuing, managing, and integrating academic credentials (21); Streamlining the credential issuance process (21); Digital identity management for students (21, 54); Employer access to verified qualifications (22); Reducing the cost of issuing academic credentials (22); Recording educational activities in a digital resume (21); Developing blockchain-based curricula, content tracking, and assessment (36); Managing student enrollment data (51).	15
Personalized, adaptive, and data-driven learning.	Personalization of learning experiences and content (21, 22); Identification of educational needs, areas requiring support, and learning styles (21, 22); Adapting programs to student progress and competencies (21, 22); Adaptive and customized learning (22); Self-regulation and adjustment of learning strategies (21); Support for continuous tracking of individual progress (21, 22); Analysis of student performance data (22); Design of targeted educational programs (21).	12
Collaborative, social, and interactive learning in a metaverse environment.	Facilitating collaborative and shared learning (21, 22); Real-time peer-to-peer interaction (21); Enabling the sharing of resources and information (21); Strengthening the sense of community, collaboration, and teamwork (31); Providing opportunities for effective mentoring (21); Simulated and interdisciplinary learning (21); Development of educational scenarios and dynamic interactive environments (21).	8
Continuous, real-time, and performance data-driven assessment.	Tracking student progress and achievements (31, 32, 42); Continuous assessment of progress and performance (31); Secure recording of performance metrics and learning outcomes (31); Real-time and periodic feedback (31, 32, 42); Secure and anonymous student assessments (31); Self-assessment by students and faculty members (31); Enhancing the accuracy of educational decision-making (31, 43, 59); Providing feedback on educational programs (42).	14
Development of key professional and interpersonal skills.	Critical thinking, problem-solving, and decision-making (21); Development of teamwork skills (21); Fostering a growth mindset and self-development (21); Exploratory learning and gamification (21); Promoting a culture of lifelong learning (21, 22, 32); Growth of online learning (51); Encouraging active engagement and continuous learning (21, 22); Enhancing self-development skills (21).	11
Optimization of educational processes and enhancement of institutional efficiency.	Reducing educational workload and accelerating tasks (22); Enhancing efficiency and productivity in education (22, 51); Improving the quality of the learning experience (21); Supporting the design of more effective curricula (21); Enhancing the accuracy of informed educational decision-making (21, 33, 49); Developing educational strategies (21); Credentialing and validation of course content (36); Supporting curriculum evaluation (36).	11

Table 5. Blockchain applications in medical research

Main themes	Key concepts	Frequency
Security, transparency, and integrity of research data.	Immutable recording of research data (22); Tamper-proof and traceable data (23); Integrity of research data (22, 28, 32); Improved reliability and accuracy of research data (22); Auditability and traceability in scientific research (22, 23); Transparency in collaborative research projects (22, 23); Enabling stakeholders to track data origins and monitor changes over time (22); Preserving confidentiality in medical research data (23); Protecting intellectual property rights in research (23).	12
Inter-institutional and interdisciplinary collaboration in research.	Strengthening collaboration among researchers (23, 26, 57); Fostering a culture of research collaboration (22); Enhancing interaction between researchers and patients in studies (55); Creating a collaborative environment for researchers (22); Promoting interdisciplinary approaches in academic research (22); Establishing a shared data repository (22); Developing a common language for data exchange in research (33); Sharing data and insights across research institutions (22); Enabling data sharing within clinical teams and between physicians and researchers (62).	11
Trust, ethics, and research accountability.	Increasing trust in research findings (22, 55); Confidence in clinical actions and data-driven decision-making (22); Promoting research ethics (22); Fostering a culture of research integrity (22); Strengthening research accountability (22); Preventing the generation of fabricated data (22); Building a culture of trust in research (22); Establishing trust among research teams (22); Enhancing the reproducibility of studies (22, 23, 50); A reliable mechanism to accelerate clinical trials (24, 36).	14
Automation, productivity, and efficiency in research processes.	Automating various research functions (22); Enhancing research productivity (40, 53); Reducing the cost of clinical trials (34); Accelerating academic research (22, 34); Boosting the pace of innovation in research (22); Improving the quality of research (22, 26, 34); Increasing research efficiency (51); Ecosystem-level support for research outputs (24); Public sharing of research findings (22); Timely interventions based on research results (22).	14
Support for research design and analytical methods.	Supporting the precise design of research methodologies (22); Helping researchers conduct deeper analyses (22); Performing advanced analytics in research (51, 67); Developing data collection methods (60); More innovative and reliable research methodologies (38); Strategic alignment of research direction (60); Discovering new ways to process research data (59); Innovation in research (22, 47); Transforming research objectives (60); Supporting feasibility studies for implementing research outcomes (63); Assisting researchers in accessing population- level insights for medical treatment (63).	13
Research data management	Research data management (22, 59); Updating research data (22); Fast and secure access to longitudinal research data (37); Open access to data in research (51); Timely access to research data (22); Generating big data for research (23); Improving the quality and quantity of data for medical research (61).	8
Clinical trial development	Clinical trial data management (34, 55, 59); More precise monitoring of clinical trials (47); Management of clinical testing processes (24); Traceability of clinical trial phases (58); Simulation of clinical trials (34); Automation of clinical data processing (34); Integration of clinical trial processes (43); Transparency in clinical trial data reporting (32, 44).	11
Governance and oversight in research.	Effectiveness in monitoring research processes (22); Management of research licensing (37); Administration of academic research (56); Transforming the peer review process for clinical research publications (50); Monitoring clinical research activities (53); Supporting compliance with research regulatory requirements (22); Sharing data with regulatory bodies (28); Monitoring individual clinical data in research (58).	8

Table 6. Blockchain applications in healthcare

Main themes	Key concepts	Frequency
Health data and records management.	Medical records management (24, 29, 30, 33, 37, 38, 40, 43, 44, 48, 50, 52, 56, 68); Healthcare data management (44, 48, 49, 54, 56); Storage, access control, and data sharing (24, 30, 32, 33, 38, 39, 42-47, 50, 51, 53, 54, 61-64, 66, 67); Integration of medical data (64); Easy retrieval of treatment information (34); Development of digital health applications (32); Patient access to their medical data and records (34, 40, 41, 48, 49, 50-52, 60, 68); Data traceability among stakeholders (29, 44, 54, 58, 64, 68); Establishing a global system for data sharing (50, 51, 53).	63

Security, privacy, and authenticity of information.	Enhancing the security and privacy of healthcare data (24, 31-38, 40-45, 46-51, 53, 55-57, 63, 67, 68); Securing patient information (35); Preventing incorrect billing (28); Reducing the risk of human error in data entry and processing (37); Identifying risks of patient data theft or manipulation of medical records (53); Combating forged electronic prescriptions (52); Preventing falsified informed consent forms (53); Managing patient consent (67, 28).	34
Pharmaceutical supply chain.	Tracking the authenticity of pharmaceuticals in the supply chain (28, 43); Verifying the authenticity of medications (28); Reducing the risk of counterfeit drugs entering the market (28-30, 32, 35-39, 43, 47, 50, 67); Enhancing transparency and trust among all stakeholders (30, 31, 35-37, 39, 49, 55, 59, 63, 68, 69); Providing a platform to track the production, distribution, and sale of medications (27-29, 31, 32, 36-38, 42, 49, 51-53, 57, 58, 63, 66, 68); Digital proof of pharmaceutical intellectual property ownership (24); Improving supply chain efficiency through automation and reduced reliance on intermediaries (24, 28, 58); Reducing costs in the production and distribution process (28, 40, 58); Innovating the pharmaceutical supply chain (28); Aligning supply and demand within the pharmaceutical supply chain (29, 35, 36, 38, 42, 47, 50, 57); Digitalization and integration of the pharmaceutical supply chain (29); Supporting pharmaceutical after-sales services (56).	62
Telemedicine and digital health services.	Telemedicine and remote monitoring (28, 32, 36, 46, 48, 50, 57, 58, 62, 63); Remote feedback to the clinical team (26, 62); Development of virtual consultation services and online platforms (32, 42); Providing real-time emergency services (32, 63).	16
Development of insurance and billing processes.	Improving the insurance claims and complaints process (24, 25, 28, 34, 36-38, 49, 64, 68); Management of medical insurance (66); Claims and billing management (24, 28, 67); Automation of all medical billing operations (30); Reducing costs and bureaucracy in the healthcare system (33, 46, 47, 49, 55, 65).	20
Improved clinical decision-making and personalized treatment.	Clinical decision support systems (29, 31, 49); Improving diagnostic accuracy and treatment effectiveness (31, 36); Accurate prediction of drug effects (40); Supporting the review of treatment plans (40); Personalization of treatment programs (40, 63); Clear and transparent access to the latest treatment information (26, 45); Reducing the occurrence of medical errors (27, 35, 43, 49); Patient-centered approach in healthcare (30, 31, 35, 38, 49, 54); Enhancing coordination in healthcare delivery (30, 36, 43); Improving patient satisfaction outcomes (30, 39, 40, 49, 52); Increasing the capacity for informed decision-making in the healthcare system (31, 33, 55, 68); Real-time monitoring and disease control (39, 61, 63, 67).	37
Interoperability and data exchange in healthcare.	Institution-centered interoperability (24, 34, 36, 38, 42, 47, 50, 53, 56, 60-62, 66, 69); Patient-centered interoperability (24); Development of immutable data protocols and a global data-sharing ecosystem (49-51, 53).	19
Smart transformation and digitalization of the healthcare system	Digitalization and integration of the healthcare system (29, 41, 47, 56); Intelligent healthcare system development (51, 67); Development of blockchain-based mobile health applications (51); Creating innovative models for data sharing (41, 42, 46, 55); Innovating disease detection processes (34); Automating and accelerating administrative processes (28, 40, 47, 65); Managing conflicts and disputes (28, 40); Adopting digital models of healthcare (39); Supporting data-driven decision-making (31); Cost management and financial planning in the healthcare system (33, 40, 46, 49, 55).	25
Continuous health monitoring, supervision, and evaluation.	Health record auditing (26); Continuous patient health monitoring without disrupting daily life (31); Tracking patient interactions with the healthcare system (26, 43); Development of timely medical alerts (33); Effective monitoring of electronic medical data (27); Digital tracking, management, and surveillance of pandemic outbreaks (27, 32, 39, 53); Data sharing with regulatory authorities (28).	11

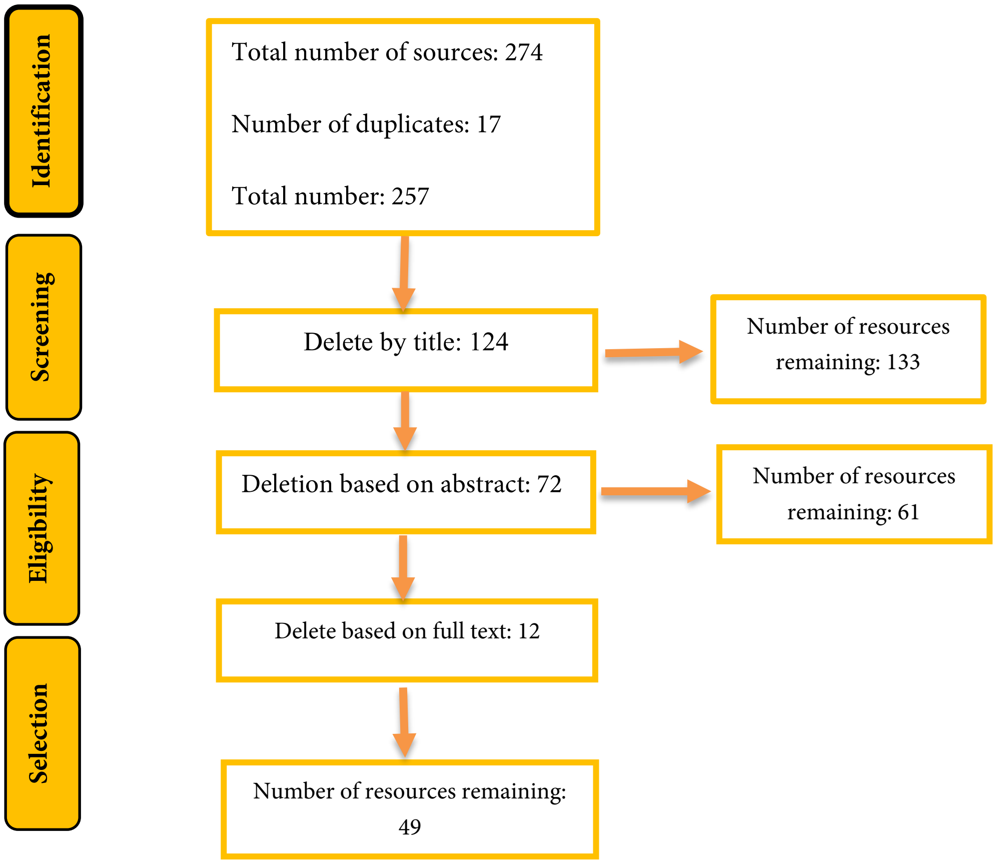

Figure 1. The PRISMA flow diagram

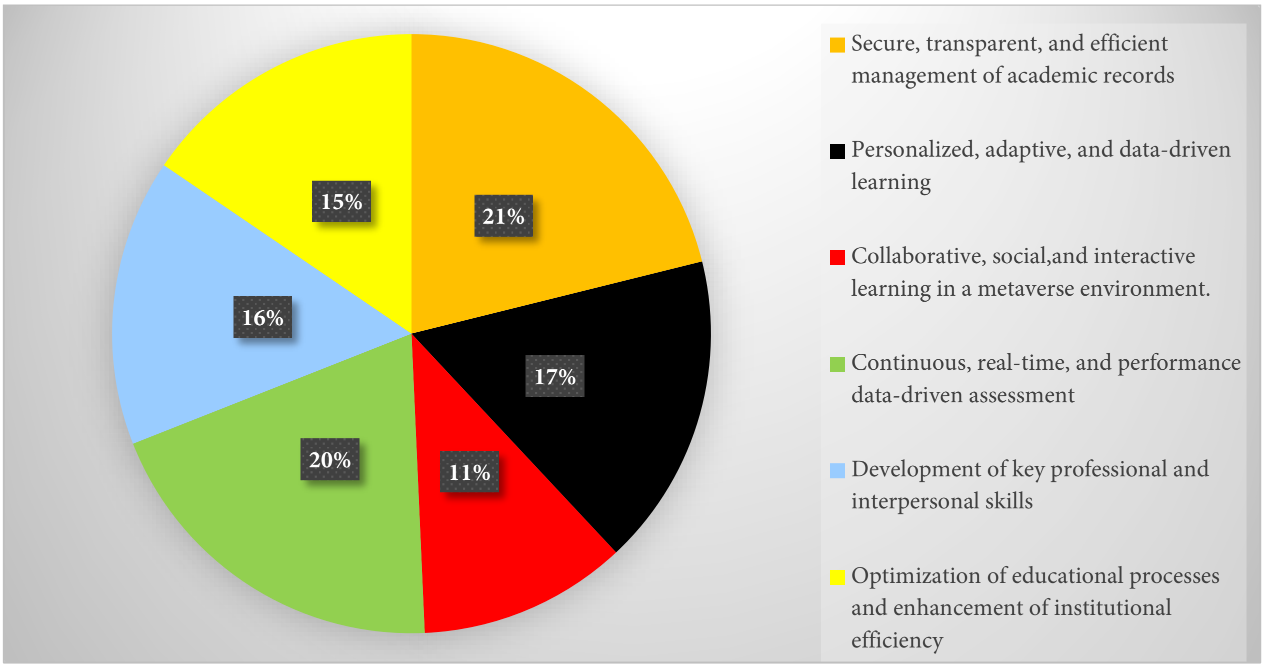

Figure 2. Blockchain applications in medical education

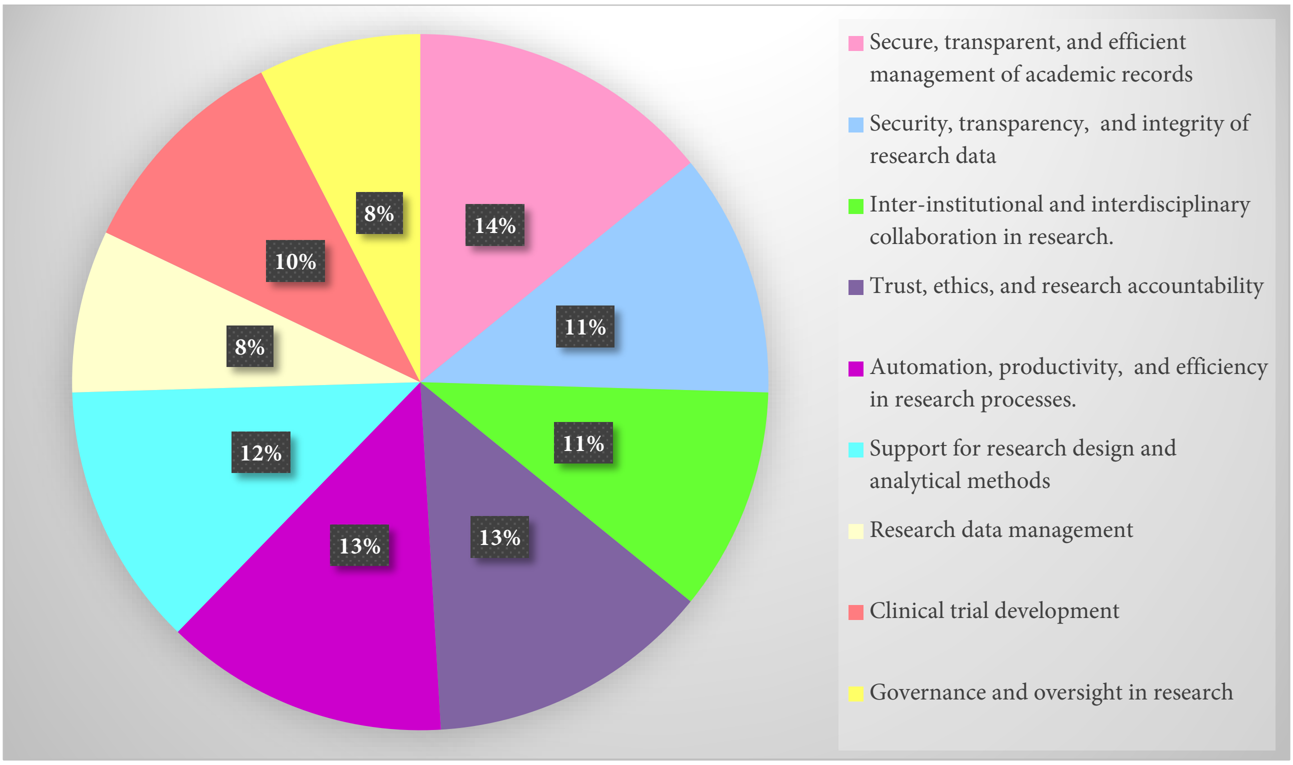

Figure 3. Blockchain applications in medical research

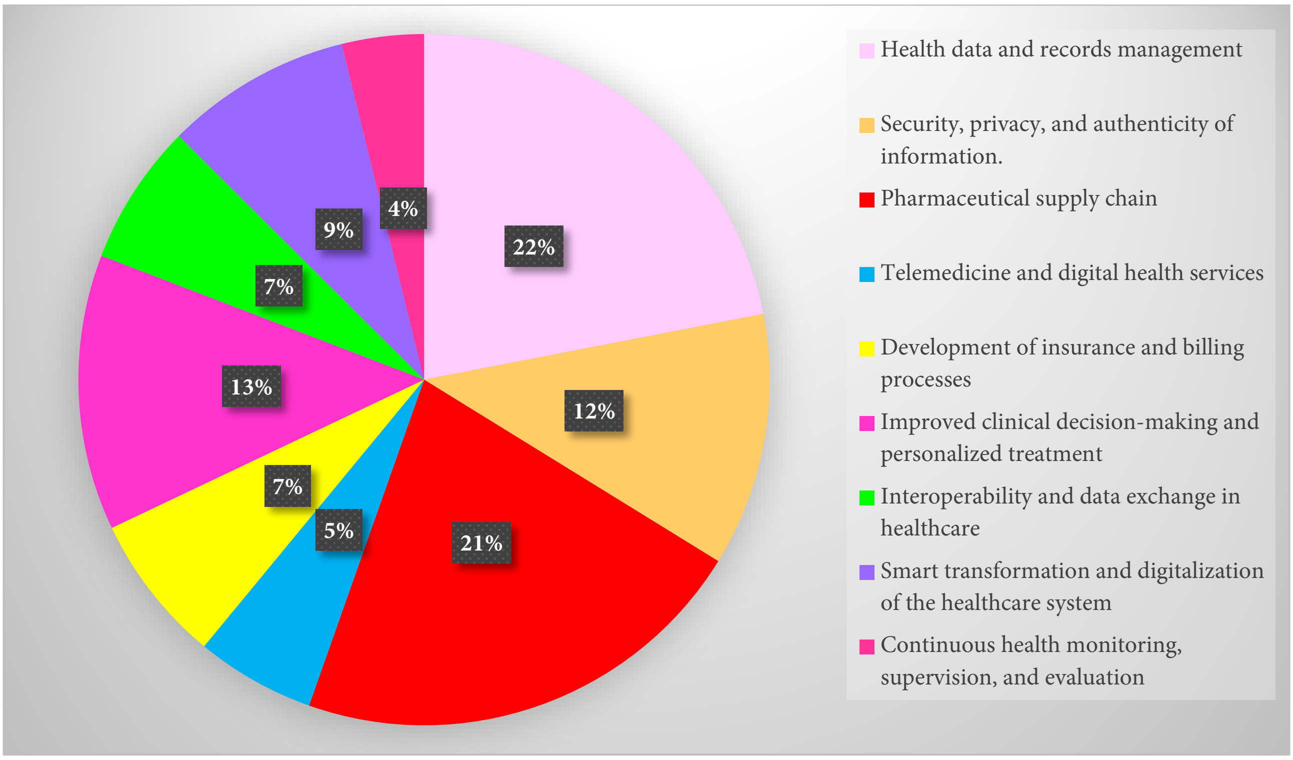

Figure 4. Blockchain applications in healthcare