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REVIEW ARTICLE

A Scoping Review of Cloud Computing Solutions in Enhanced Dialysis Information Exchange

Asghar Ehteshami [1], Maedeh Esmailzadeh[1],Abolfazl Rezaei [1]*

[1] Health Information Technology Research Center, Isfahan University of Medical Sciences, Isfahan, Iran

ABSTRACT

Background: Dialysis, a critical treatment for kidney failure, faces challenges related to patient safety, treatment efficiency, and overall care quality. Despite advancements in technology, improved information exchange is essential to overcome limitations of traditional sharing methods, which often lack accessibility and security. Cloud computing offers a promising solution with its scalability and efficiency, potentially revolutionizing dialysis information exchange and leading to improved patient outcomes and enhanced healthcare delivery.

Methods: This scoping review aimed to synthesize research on cloud computing solutions for improving dialysis information exchange by conducting a systematic search across five databases (PubMed, Web of Science, Scopus, Embase, and ProQuest) using relevant keywords. The review included observational studies published from 2010 to the present, and employed a rigorous selection process to ensure the studies were pertinent to dialysis care while excluding irrelevant articles.

Results: Six key areas where cloud computing can enhance dialysis information exchange were identified: telemedicine, cloud computing infrastructure, clinical information systems, information management, standards and models, and associated challenges. It emphasizes the potential of cloud-based solutions to improve patient care through remote monitoring, data analytics, and improved communication among healthcare providers.

Conclusions: Cloud computing solutions present a promising opportunity to enhance dialysis information exchange by improving security, transparency, cost-effectiveness, and efficiency. This review highlights the potential of cloud-based platforms to streamline data management, facilitate communication, and enhance patient care. However, realizing these benefits requires addressing challenges such as data security, establishing unified standards, and ensuring interoperability. By integrating advanced technologies like blockchain, attribute-based encryption, and federated learning, and prioritizing research on data privacy concerns, the advantages of cloud computing in dialysis care and improve patient outcomes. Can be further unlocked.

Keywords: Dialysis , Hemodialysis , Information Exchange ,Cloud Computing

Introduction

Dialysis, a crucial treatment for renal failure, has advanced significantly since its inception in the early 20th century. Hemodialysis and peritoneal dialysis are now standard treatments for chronic renal failure (1). However, this disease presents various risks and complications that healthcare professionals must diligently address to ensure patient safety. In the complex dialysis environment, human errors, communication breakdowns, and protocol non-compliance can lead to serious side effects such as embolism, infections, and medication errors (2-4). Technical issues, including contaminated dialysis sets and errors in solution composition, can also contribute to these complications, highlighting the critical role of physicians in closely monitoring the dialysis process and promptly addressing any problems that arise during hemodialysis sessions

Corresponding Author: Abolfazl Rezaei
Email: Abolfazlrezaei2013@yahoo.com
Tel: +98 9135223849
School of Management and Medical Information, Isfahan University of Medical Sciences, Isfahan, Iran

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(5). The burden of dialysis can significantly impact patients' lives, often leading to a decreased quality of life and shorter life expectancy compared to the general population(1). Looking ahead, advancements in dialysis technology and a focus on environmental sustainability are expected to improve the effectiveness and long-term viability of treatment in the coming years (6).

Information exchange is crucial in therapeutic environments, particularly in dynamic and competitive settings. Effective communication and knowledge sharing are essential for achieving balanced feedback strategies, fostering individual and collective knowledge within organizations (7), enhancing communication skills in professional environments, and developing competitive advantages in supply chains. Furthermore, it promotes cooperative behavior within networks (8). Information exchange facilitates the sharing of both explicit and tacit knowledge, leading to more favorable social balances, significant improvements in green supply chains, and a deeper understanding of cooperative dynamics in interdependent networks (9). The importance of information exchange in dialysis care is evident from multiple perspectives. Platforms like dialysis-connect enable seamless communication between care environments, enhancing continuity of care for dialysis patients (10). Advances in dialysis techniques have demonstrated the critical need for improved hemodialysis practices to reduce complications and increase patient survival rates(11). Bedside terminals in dialysis units provide access to critical information and facilitate treatment, while server-based systems enable accurate data collection, quality control, and continuous monitoring of treatment outcomes (12). The serious nature of end-stage renal disease underscores the vital role of information exchange in providing comprehensive and effective care for kidney patients (13).

Cloud computing offers a scalable and efficient platform for data sharing, revolutionizing information exchange and enabling the creation of intelligent, interactive systems that enhance user experience and facilitate seamless information flow (12). Cloud-based data exchange employs connection, forwarding and auditing rules to ensure secure and efficient data transfer (14). Furthermore, cloud computing provides numerous technical advantages, including enhanced resource access, advanced programming models, and sophisticated task scheduling capabilities, making it a leading model for accessing information and services in the digital age (15). In the context of dialysis care, cloud computing plays a vital role in improving patient outcomes. For instance, advanced cloud-based technologies like optical sensing devices (OSD) and machine learning (ML) models can empower doctors to predict changes in relative blood volume during dialysis treatments, enabling timely preventive interventions (16). Web-based information exchange platforms, such as dialysis-connect, exemplify the potential of cloud computing in dialysis. These platforms integrate patient information and facilitate seamless sharing between healthcare providers, increasing efficiency, reducing patient waiting times, promoting continuity of care, and potentially minimizing hospitalizations (10).

The goal of promoting dialysis information exchange through cloud computing is to enhance the efficiency and effectiveness of dialysis treatment (17). While computer-aided medical activities in nephrology and dialysis, such as tele-dialysis programs, have demonstrated promising results in optimizing clinical supervision, technical aspects, and managerial effectiveness of dialysis units (18), the potential of cloud-based systems extends further. By leveraging data mining techniques to cluster patient information, healthcare providers can gain valuable insights that improve decision-making processes and enhance dialysis adequacy (19). Cloud-based systems streamline processes, enable remote patient monitoring, facilitate seamless data sharing, and foster improved communication among healthcare providers. This scoping review

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aims to synthesize existing research on cloud computing solutions for enhancing dialysis information exchange.

Materials and Methods

The research question was formulated based on relevant keywords and their synonyms, and was identified through a comprehensive search of MESH and EMTREE databases.

Studies related to the identified keywords were searched using the following strategies across the PubMed, Web of Science (WOS), Scopus, Embase, and ProQuest databases.

Table 1. Related keywords and synonyms used in the search for studies on cloud computing solutions for dialysis information exchange

keyword	Synonyms
Dialysis	dialys*, haemodialys*, hemodialys*, kidney dis*, kidney failure, kidney insufficienc*, renal disease*, renal failure*, renal insufficienc*, ESRD
Information exchange	data shar*, data exchange*, health information exchange*, information exchange*, medical information exchange*
Cloud computing	cloud process*, cloud service*, cloud storage*, cloud comput*, cloud service*, cloud solut*, cloud infrastruc*, cloud based system*

Table 2. Search strategy for identifying relevant studies

Data base	Search strategy
PUBMED:	(dialys*[Title/Abstract] OR haemodialys*[Title/Abstract] OR hemodialys*[Title/Abstract] OR kidney dis*[Title/Abstract] OR kidney failure*[Title/Abstract] OR kidney insufficienc*[Title/Abstract] OR renal disease*[Title/Abstract] OR renal failure*[Title/Abstract] OR renal insufficienc*[Title/Abstract] OR ESRD[Title]) OR (Data shar*[Title/Abstract] OR Data exchange*[Title/Abstract] OR Health Information Exchange*[Title/Abstract] OR Information Exchange*[Title/Abstract] OR Medical Information Exchange*[Title/Abstract]) AND (cloud process*[Title] OR cloud service*[Title] OR cloud storage*[Title] OR cloud comput*[Title] OR Cloud solut*[Title] OR Cloud infrastruc*[Title] OR Cloud based system*[Title])
EMBASE:	(dialys*:ab,ti OR haemodialys*:ab,ti OR hemodialys*:ab,ti OR 'kidney dis*':ab,ti OR 'kidney failure*':ab,ti OR 'kidney insufficienc*':ab,ti OR 'renal disease*':ab,ti OR 'renal failure*':ab,ti OR 'renal insufficienc*':ab,ti OR esrd*:ab,ti OR 'data shar*':ab,ti OR 'data exchange*':ab,ti OR 'health information exchange*':ab,ti OR 'information exchange*':ab,ti OR 'medical information exchange*':ab,ti) AND ('cloud process*':ti OR 'cloud service*':ti OR 'cloud storage*':ti OR 'cloud comput*':ti OR 'cloud solut*':ti OR 'cloud infrastruc*':ti OR 'cloud based system*':ti)
WEB OF SCIENCE:	(TS=dialys* OR TS=haemodialys* OR TS=hemodialys* OR TS="kidney dis*" OR TS="kidney failure*" OR TS="kidney insufficienc*" OR TS="renal disease*" OR TS="renal failure*" OR TS="renal insufficienc*" OR TS=ESRD* OR TI="data shar*" OR TI="data exchange*" OR TI="health information exchange*" OR TI="information exchange*" or TI="medical information exchange*") AND (TI="cloud process*" OR TI="cloud service*" OR TI="cloud storage*" OR TI="cloud comput*" OR TI="Cloud solut*" OR TI="Cloud infrastruc*" OR TI="Cloud based system*")
SCOPUS:	(TITLE (dialys*) OR TITLE (haemodialys*) OR TITLE (hemodialys*) OR TITLE ("kidney dis*") OR TITLE ("kidney failure*") OR TITLE ("kidney insufficienc*") OR TITLE ("renal disease*") OR TITLE ("renal failure*") OR TITLE ("renal insufficienc*") OR TITLE (esrd) OR TITLE ("data shar*") OR TITLE ("data exchange*") OR TITLE ("health information exchange*") OR TITLE ("information exchange*") OR TITLE ("medical information exchange*")) AND (TITLE ("cloud process*") OR TITLE ("cloud service*") OR TITLE ("cloud storage*") OR TITLE ("cloud comput*") OR TITLE ("Cloud solut*") OR TITLE ("Cloud infrastruc*") OR TITLE ("Cloud based system*"))
PROQUEST:	(title(dialys*) OR title(haemodialys*) OR title(hemodialys*) OR title("kidney dis*") OR title("kidney failure*") OR title("kidney insufficienc*") OR title("renal disease*") OR title("renal failure*") OR title("renal insufficienc*") OR title(esrd) or title("data shar*") OR title("data exchange*") OR title("health information exchange*") OR title("information exchange*") OR title("medical information exchange*")) AND (title("cloud process*") OR title ("cloud service*") OR title("cloud storage*") OR title("cloud comput*") OR title("cloud solut*") OR title("cloud infrastruc*") OR title("cloud based system*"))

This scoping review examined observational studies, including cross-sectional studies, case reports, case series, cohort studies, case-control studies, intervention studies, and related qualitative studies, published from January 2010 to the present. The focus was on studies exploring the use of cloud computing and information exchange in the field of dialysis.

Results

Articles were initially screened for relevance to the review's objectives, focusing on those investigating the impact of cloud computing on information accuracy, data management, and facilitating information transfer within dialysis treatment processes. Studies lacking a review format or unrelated to cloud computing in healthcare, particularly in dialysis, were excluded. Full-text articles were obtained for those deemed relevant. If full text was unavailable, the article was removed from consideration. Subsequently, full-text articles were further screened, excluding those published in languages other than English, editorials, letters to the editor, commentaries, and press articles due to their non-scientific nature and lack of relevance to the review's scope. Articles focusing on cloud computing in genomics without a direct connection to patient care were also excluded. This rigorous selection process allowed for a comprehensive analysis of the current state of research on cloud computing in healthcare, extracting key messages from eligible publications. Figure 1 illustrates the search and selection process for studies.

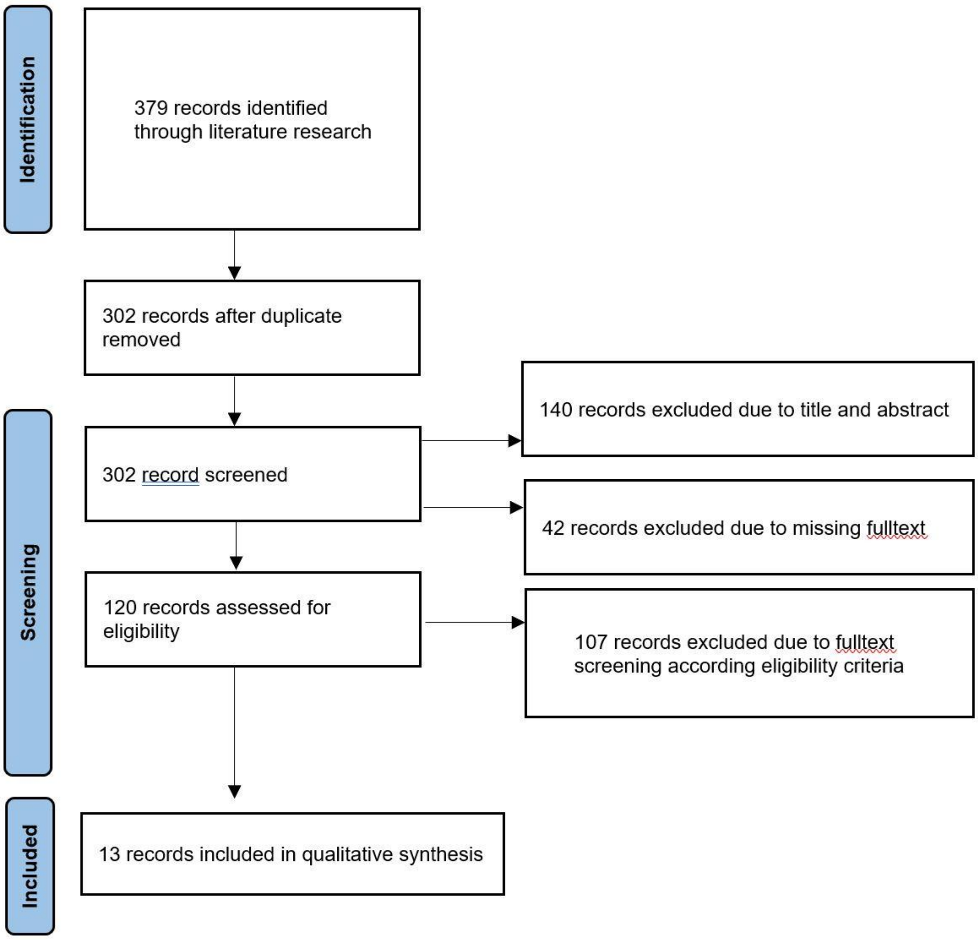

Figure 1. Flowchart of the literature search and selection process

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Six key areas where cloud computing can enhance dialysis information exchange were identified through a comprehensive review of articles, which were coded and thematically analyzed using a qualitative approach.

1. Telemedicine
2. Cloud computing
3. Information sharing and clinical information systems
4. Information management
5. Standards and models
6. Challenges

1. **Telemedicine**

Telemedicine plays a crucial role in healthcare by facilitating communication and data sharing among stakeholders. Cloud-based telemedicine systems by leveraging scalable and secure infrastructure promote collaboration between healthcare organizations and improve treatment outcomes through data analytics (20).

Griebel et al. (21) explored how cloud computing could enhance ECG monitoring and analysis, proposing standardized prehospital ECG transmission protocols and hybrid cloud environments to optimize data storage and processing from personal health sensors. These methods aim to improve ECG data analysis efficiency and scalability, reduce costs, and extend mobile device battery life via cloud-based offloading(21).

The integration of telemedicine into dialysis care has demonstrated significant potential to enhance patient outcomes and monitoring efficiency. By facilitating remote patient monitoring, telemedicine proves particularly beneficial for dialysis patients, offering continuous oversight and timely interventions. This is underscored by several key factors: advanced patient monitoring, where real-time monitoring of home dialysis patients improves condition management (22) remote systems like automated peritoneal dialysis which reduce complications and boost survival rates (23), improved communication and support, as telemedicine fosters better provider-patient interactions, enhancing the care experience and increasing confidence and satisfaction (24) , affordability and accessibility, with telemedicine reducing healthcare costs by minimizing hospital visits and optimizing resources, becoming especially vital during the COVID-19 pandemic for maintaining continuous care while adhering to social distancing (25).

2. **Cloud computing**

Cloud computing is a comprehensive framework that combines hardware and software to deliver diverse services over the Internet. By providing computing solutions and virtual storage, this technology has revolutionized information technology management in the healthcare industry, providing medical facilities with flexibility in accessing information resources (26).

The Internet of Things (IoT) has revolutionized communication between objects, but data sharing is challenged by inconsistencies in data quality. Cloud computing provides the necessary infrastructure to support IoT, but security concerns hinder its widespread adoption. For this reason, users of IoT devices with limited capabilities are turning to public cloud storage to reduce data transfer costs (27).

Cloud computing can significantly improve patient care. Using Software as a Service (SaaS), providers can access real-time patient data and make better decisions. Integrating data sources into cloud platforms improves patient outcome monitoring and resource management (28).

3. **Information sharing and clinical information systems**

Effective data sharing is essential for advancing knowledge in dialysis treatment. By establishing unified standards and formats, cloud platforms facilitate the efficient use of data and avoid duplicated efforts among care providers. Additionally, dialysis facilities can more quickly develop essential information systems, reduce costs, and improve the efficiency of data utilization (27, 29).

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Health Information Exchange (HIX) enhances healthcare delivery through cloud computing by providing integrated medical information services. Utilizing a medical knowledge base, HIX enables real-time access to patient data, thus improving doctor-patient interactions. Cloud infrastructure not only facilitates efficient data management but also improves collaboration among care teams, reduces operational costs, and enhances patient care (28, 30).

The security of electronic health record (EHR)-based systems, especially for computerized physician order recording in health information exchange (HIE) for dialysis, is crucial. Risks such as sharing incorrect information and experiencing delays in HIE implementation can compromise patient safety. Therefore, stakeholders must address these issues when integrating cloud-based HIE solutions in dialysis to ensure accurate and timely data exchange (31-33).

4. **Information management**

In information management, a standardized system is essential for fostering collaboration among data owners, cloud service providers, and authorized users. This framework ensures secure and efficient information sharing, leading to improved data governance and better decision-making. By implementing such standards, organizations can effectively manage their data assets and support innovation in various sectors, including healthcare, finance, and education (27, 34).

Just as PACS revolutionized radiology, effective data management in dialysis hinges on implementing data standards. Standardizing dialysis data—including patient demographics, treatment parameters, and laboratory results—is crucial for seamless data exchange and analysis, ultimately increasing data quality and operational efficiency (32).

The HIX cloud service platform is crucial for the dialysis sector, providing a comprehensive information management strategy that enables detailed analysis of procedures, results, and physician orders. These insights help optimize treatment plans and enhance the quality of care while ensuring strong governance of sensitive information, such as medical history and billing data (28). With features like system management, policy enforcement, and role-based access control, the platform maintains data integrity and regulatory compliance, meeting the specific needs of dialysis facilities and improving resource allocation, operational efficiency, and patient outcomes in a secure environment (26, 35).

5. **Standards and models**

Standardized protocols, mirroring the success of PACS in radiology, are essential for effective data exchange in dialysis using cloud computing. These protocols must include detailed standards for sharing critical information like medical history, lab results, and treatment reports via cloud systems. Adhering to these standards ensures secure communication among dialysis providers (32).

The MapReduce programming model is highly efficient for processing dialysis data in cloud-based environments. By distributing data across multiple cloud nodes and leveraging Map and Reduce functions for parallel processing, this model facilitates efficient collection and analysis of patient data and treatment outcomes (31).

A framework integrating IoT, cloud computing, and big data analytics can overcome the challenges of developing dialysis data exchange applications. This three-layered framework uses IoT sensors to collect real-time vital signs, cloud computing for data sharing, and big data analytics to extract actionable insights. Leveraging these technologies empowers healthcare providers to enhance patient safety, reduce errors, and deliver high-quality care, even in challenging environments (26).

A successfully developed and implemented machine learning model requires a focus on customer value and awareness. By integrating such a model, healthcare organizations can gain a competitive advantage and effectively address patient needs. The model should be designed to capitalize on business opportunities and foster

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long-term relationships, ultimately improving patient outcomes and reducing errors (11, 28).

6. **Challenges**

Key challenges in exchanging dialysis data via cloud computing included ensuring data quality and reliability, protecting sensitive patient information, and effectively analyzing large datasets (26).

Balancing robust data security with the need for seamless information sharing is crucial in cloud-based dialysis data exchange. Storing sensitive patient data on cloud platforms introduces security risks, such as potential attacks, necessitating strong encryption and careful review of security protocols and data sharing mechanisms. This careful approach is essential for maintaining both patient privacy and operational efficiency in dialysis care (27).

Creating a dynamic and adaptable file transfer system poses a significant challenge for cloud-based dialysis data exchange. This system must accommodate network fluctuations and varying data sizes while adhering to strict time constraints for critical health information. Achieving timely and reliable data transmission requires sophisticated algorithms and adaptive solutions (20).

Discussion

Analysis demonstrates that the blockchain approach significantly outperforms existing methods regarding transaction throughput, computational and communication costs, and secure data storage and sharing. These findings highlight blockchain technology's potential to revolutionize health information exchange in cloud environments, enabling faster, safer, and more efficient data sharing (33).

Taiwan's MediCloud system, a cloud-based medical information exchange platform, has significantly improved healthcare delivery. Government incentives have driven increased system utilization, resulting in shorter emergency department stays, enhanced medication safety, and effective patient information management during the COVID-19 pandemic. Furthermore, MediCloud increases patient engagement through My Health Bank, reduces costs by minimizing redundant imaging, and ensures high user satisfaction. However, challenges remain, including incomplete acceptance data and the need for further research to establish a direct link between MediCloud utilization and improved dialysis care quality (34).

Madanian et al.(26) proposed a cloud-based framework utilizing IoT devices and big data analytics to enhance disaster healthcare. This framework collects real-time data from critical areas, securely stores it in the cloud, and leverages analytics to generate actionable insights, thereby improving resource allocation and enabling more effective interventions (26).

Zhang et al.(11) developed a cloud-based machine learning model for real-time prediction of dangerous intradialytic hypotension (IDH). By analyzing factors such as blood pressure and flow velocity, this model outperforms previous methods, alerting clinicians to potential issues and enabling preventive measures (11).

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Table 3. Comparative table of results and key models from each study

Aspect	Blockchain approach	MediCloud system	IoT and big data framework	Machine learning model for dialysis
Primary focus	Health information exchange using blockchain technology	Cloud-based medical information exchange system	Improving disaster healthcare through IoT and big data analytics	Real-time prediction of intradialytic hypotension (IDH) during dialysis
Key benefits	High transaction throughput, reduced computational and communication costs, secure data storage and sharing	Improved healthcare delivery, shorter emergency stays, medication safety, patient engagement	Enhanced disaster preparedness and response, better resource allocation, effective collaboration	Accurate prediction , proactive alerts for IDH, better than previous methods
Operational efficiency	Faster, safer, more efficient data sharing in health information exchange	Reduced costs by eliminating redundant imaging, user satisfaction	Increased preparedness, resource allocation, and intervention effectiveness	Enables proactive interventions, real-time alerts for clinicians
Challenge/ limitations	Further research needed to confirm benefits and optimize for dialysis use	Incomplete acceptance data, need more research to confirm direct impact on dialysis care quality	Requires effective collaboration and planning among healthcare providers	Study design limitations, lack of specific data, need for optimization and validation
Impact on Patient Care	Potential improvement in patient care and operational efficiency	Enhanced medication safety, effective patient information management during COVID-19	More effective disaster healthcare interventions	Potential improvement in IDH rates and patient outcomes
Unique Features	Secure blockchain technology for data exchange	Government incentives, My Health Bank for patient engagement	Real-time data collection from IoT devices, big data analytics for actionable insights	Real-time analysis of blood pressure and flow velocity, alerts for potential IDH
Research/development needs	Further validation and exploration of blockchain's impact on healthcare	More research needed to confirm impact on emergency care	Continued development for improved disaster response	Further research to optimize and validate model across diverse patient populations

Conclusion

Cloud computing solutions offer significant improvements in dialysis data exchange, enhancing security, transparency, cost-effectiveness, and efficiency. However, addressing existing challenges and integrating advanced technologies are crucial to realizing the full potential of these healthcare solutions.

1. Enhanced security and transparency: A proposed blockchain-based framework facilitates secure and transparent exchange of sensitive dialysis data. Leveraging advanced cryptographic techniques, including Proof-of-Stake consensus, SHA256 hashing, and ECDSA, this framework verifies transactions and guarantees data integrity and authenticity. Its hybrid approach enhances

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both security and scalability, providing a robust solution for effective dialysis information management (33).

2. Cost-Effectiveness and interoperability: Cloud-based systems for generating and integrating clinical documents offer cost-effective solutions to interoperability challenges and cost barriers associated with traditional electronic health record systems. These platform-independent and scalable systems are compatible with IHE XDS and well-suited for integrating patient electronic health records (35).

3. Scalability and Efficiency: Cloud computing provides the necessary infrastructure and scalability for managing dialysis data, empowering healthcare providers with timely insights and improving patient care quality. Health information exchange (HIX) platforms enhance hospital efficiency, facilitate communication between doctors and patients, and reduce costs and IT burdens (28, 31).

4. Advanced encryption and data management: Attribute-based encryption (ABE) and lattice-based Identity-Based Broadcast Encryption (IBBE) offer efficient and secure solutions for data sharing in cloud-based healthcare systems. Implementing these methods enhances the security and efficiency of data exchange across diverse care environments (27).

5. Synergistic integration of technologies: Integrating the Internet of Things (IoT), cloud computing, and big data analytics can significantly improve dialysis information exchange. However, realizing the full potential of these technologies requires robust frameworks and protocols to protect sensitive patient data and address privacy concerns (29).

6. Broader impact: Cloud-based HIX platforms offer substantial benefits to hospitals, patients, and healthcare providers. Patients gain improved access to medical information and streamlined processes, while these platforms enhance service efficiency, reduce costs, and improve communication within healthcare systems (21, 26).

7. Challenges and future directions: Despite the numerous benefits of cloud computing in healthcare, challenges persist, including a lack of unified standards, data security concerns, and variations in service quality (32). Future research should prioritize increasing storage capacity, integrating federated learning, and enhancing multilingual support and security in multi-user environments.

Ethical Considerations

In this review, we attempted to evaluate the literature based on scientific criteria and not on non-scientific factors such as gender, race, ethnicity, religion, or socioeconomic status. We also attempted to evaluate the literature with respect to the needs and interests of dialysis patients and stakeholders.

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Conflict of Interests

The authors declared no conflict of interests.

Authors' Contributions

A.R conceptualized and designed the research, supervised the research process, and contributed to data analysis and interpretation. M.E performed data collection, conducted the primary analysis, and drafted the initial manuscript. A.E provided critical revisions, assisted in data interpretation, and contributed to finalizing the manuscript. All authors read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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