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Review Article

Global Development Landscape of Cross-Border Medical Data Sharing: Security Vulnerabilities,

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Abstract

This paper reviews the applications of cross-border medical data sharing in clinical practice, medical research, and public health, synthesizes information from various texts, summarizes its developmental value, challenges, and coping strategies, and discusses its new characteristics and future research trends based on literature. It is found that cross-border medical data sharing significantly promotes global medical progress by accelerating disease research, improving the accuracy of personalized medicine, and optimizing public health emergency responses. However, its development faces three core challenges: security vulnerabilities, legal conflicts, and technical barriers. Future breakthroughs need to rely on technology-legal-governance synergy: combining blockchain with attribute-based encryption to achieve dynamic desensitization and fine-grained access control; using regional agreements to bridge regulatory gaps; and enforcing data standardization through hierarchical interoperability frameworks. Only by building a closed-loop governance system can the balance between data sovereignty and research collaboration needs be achieved, thereby unlocking the global health potential of cross-border sharing.

Keywords: Cross-border medical data sharing; Legal compliance conflict; Privacy-enhancing technology; Hierarchical interoperability.

Introduction

Cross-border medical data sharing refers to the coordinated processing and transmission of health-related data between institutions in different jurisdictions during global public health emergencies, involving compliant data flows based on specific legal instruments, while needing to overcome obstacles caused by differences in international ethical and legal frameworks. Its core goal is to support disease control decisions and public health interventions, with emphasis on data subjects, technical implementation, and legal foundations [1,2]. The application value of cross-border medical data sharing is mainly reflected in three aspects: 1. Clinical value: Palchuk et al. [3] proposed the construction of global federated medical data analysis platforms to support cross-border collaboration. Studies have also summarized practical guidelines for medical data openness based on the EU GDPR, and mentioned that the US NIH has mandated data sharing plans for funded projects since 2023 to promote the FAIRification of clinical data [3,4]. 2. Innovation value in medical research: Teng et al. [5] proposed a blockchain architecture combining attribute-based encryption technology and privacy computing models to achieve traceability, auditability, and hierarchical access control of medical data. Meanwhile, the application of technologies such as blockchain ensures the secure sharing and traceability of research data [5-7] 3. Public health value: During global health emergencies such as the COVID-19 pandemic, cross-border data sharing significantly accelerated the implementation of disease control decisions and public health interventions [8,9].

In reality, cross-border medical data sharing also faces many difficulties today. Legal and compliance differences: Cross-border health data sharing faces differences in international ethical and legal frameworks, and inconsistent interpretations of the EU GDPR lead to a lack of consensus and coordination in data sharing, increasing compliance burdens [1,9]. Privacy and security risks: The risk of data re-identification in cross-border sharing increases compliance complexity. Moreover, privacy leakage risks

and single points of failure in medical data sharing make it difficult to ensure data security during cross-border sharing. Traditional sharing models rely on permission reviews, and bureaucratic procedures increase time and resource costs, thereby affecting the efficiency of cross-border collaboration [4,10,11]. Technical and interoperability barriers: The lack of interoperability and common data models complicates legal data sharing, leading to inefficient cross-border flow of health data [12].

Based on the above investigation, this review concludes that the core contradiction of cross-border medical data sharing lies in the conflict between "data sovereignty" and "needs for research collaboration", and its fundamental goal is to support disease control decisions and intervention measures in global public health emergencies. However, differences in legal frameworks and technical barriers have seriously hindered the achievement of this goal.

Application Value of Cross-border Medical Data Sharing

Clinical Application Value

Cross-border medical data sharing has significant value in clinical applications. Firstly, it accelerates disease research and drug development. For example, through global data sharing initiatives, federated data analysis pipelines can integrate transnational data resources to promote large-scale clinical research, thereby accelerating the discovery and validation of new therapies and providing more effective treatment strategies for rare diseases and chronic diseases [13]. Secondly, in public health emergencies, cross-border data sharing can quickly support drug research and development and resource allocation decisions. Through open clinical trial data platforms, it enables the rapid dissemination and validation of drug innovations, optimizes the allocation of intensive care resources and the supply of diagnostic tests, directly improving crisis response efficiency and saving lives [1,14].

In addition, cross-border sharing of genomic data supports personalized medical applications, improving diagnostic accuracy and treatment targeting through secondary data use, especially in the fields of hereditary diseases and cancer, helping to develop precision medical plans and reduce the risk of misdiagnosis [10]. Meanwhile, sharing digital medication records ensures the continuity and accuracy of medical information, reduces medication errors and adverse reactions, and improves patient safety and quality of care [15]. Finally, establishing standardized legal and ethical frameworks can simplify cross-border data transmission, enhance trust in international cooperation, and promote the sustainable development of the global health data ecosystem, ultimately achieving large-scale benefits in clinical research and overall improvement in public health [1]. In summary, these values not only promote medical progress but also directly optimize clinical practice and improve patient outcomes.

Innovation Value in Medical Research

Cross-border medical data sharing plays an important role in accelerating the process of medical research. It significantly shortens research cycles, especially in the field of rare diseases. Through global collaboration, research and development time can be reduced by 60%, breaking through geographical data limitations and promoting the rapid validation and optimization of treatment plans [16]. Meanwhile, Europe has proposed the construction of cross-national data platforms to integrate clinical, research, and industrial resources, forming high-quality datasets to support drug research and development and precision medical innovation, and emphasizing the protection of sharing security and fair benefit distribution through standardized frameworks [4,17]. Practices in China have shown that blockchain and dynamic anonymization technologies can balance privacy and efficiency.

Data in 2023 showed that the annual growth rate of medical data sharing reached 200%, providing a traceable and tamper-proof technical foundation for cross-border collaboration [4,18]. In establishing a "fair benefit" mechanism, it is necessary to ensure that medical systems receive reasonable returns in public-private partnerships, clarify rights and responsibilities through data sharing agreements, avoid commercial exploitation, and enhance public trust [19,20]. In summary, cross-border medical data sharing has become a key engine driving global medical research innovation by breaking data silos, strengthening technical guarantees, and improving ethical governance.

Public Health Value

Cross-border medical data sharing is crucial in responding to global health emergencies. It supports disease surveillance, resource allocation, and intervention decision-making through real-time exchange of epidemiological and clinical data, thereby controlling disease outbreaks and reducing public health risks. For example, data sharing can accelerate drug research and development, optimize the allocation of intensive care resources, and improve understanding of the effectiveness of preventive measures, which is particularly prominent in global emergencies [8]. Recent systematic reviews have emphasized that such sharing mechanisms can enhance regional coordination and transparency. For example, in Africa and Southeast Asia, the establishment of legal frameworks and interoperability standards has promoted the rapid flow of data, supporting timely public health responses [1]. Secondly, data sharing drives scientific research innovation and knowledge translation, improving the efficiency and quality of public health research. Recent studies have pointed out that open data policies promote data reuse and validation, accelerate the development and validation of new therapies, and maximize

public health benefits. For example, the application of FAIR principles (Findable, Accessible, Interoperable, Reusable) ensures data quality, supports cross-border collaborative research, thereby reducing duplication of work and improving scientific output [21]. In addition, the promotion of interoperability standards makes data exchange between different systems more efficient and enhances the resilience of global disease surveillance networks [22]. Furthermore, sharing mechanisms strengthen international cooperation and public trust, addressing privacy and equity issues through ethical and legal governance. In summary, the public health value of cross-border medical data sharing lies in its ability to enhance global health resilience, but it needs to combine interoperability, ethical governance, and public participation to maximize benefits.

Summary

Cross-border medical data sharing accelerates disease research and drug development in clinical applications, promotes the discovery of new therapies through global data integration such as federated platforms, and supports rapid decision-making and resource optimization in public health emergencies. Genomic data sharing improves the accuracy of personalized medicine and reduces the risk of misdiagnosis, while blockchain technology ensures data security and continuity. In medical research, sharing shortens the research and development cycle by 60%, especially promoting innovation in rare disease treatment, and enhances trust through fair benefit mechanisms. In terms of public health, it strengthens global disease surveillance and response capabilities, relying on interoperability standards and ethical frameworks to enhance resilience. Overall, it promotes international cooperation and medical progress.

Database category	literature quantity	proportion	Represent journal/publisher
SCI/SSCI journals	26	54.20 %	Nature Medicine, BMJ, The Lancet Digital Health, NPJ Digital Medicine
PubMed index journals	7	14.60 %	JAMIA Open, Orphanet Journal of Rare Diseases, Yearbook of Medical Informatics
IEEE/IET publishes	3	6.30 %	IEEE Journal of Biomedical and Health Informatics, PeerJ Computer Science
Report of International Organizations	2	4.20 %	European Commission (Official report of the European Union)
Engineering Index (EI) journal	1	2.10 %	Journal of Management in Engineering
Other Sources	9	18.80 %	Local journals and conference proceedings of various countries, etc
total	48	100 %	-

Table 1: Literature Inclusion of this article.

Difficulties and Constraints Faced by Cross-border Medical Data Sharing

Legal and Compliance Differences

There are fundamental differences in the legal definitions and protection scopes of "health data" among countries, leading to conflicts in anonymization standards and ambiguous cross-border transmission compliance boundaries [23]. Such legal differences further amplify operational complexity: the strict localization requirements of the EU GDPR conflict with rules such as HIPAA, forcing institutions to rely on cumbersome Standard Contractual Clauses (SCCs) and superimpose technical measures. Moreover, the assessment of the protection level of recipient countries required by Article 45 of the GDPR takes 3-6 months [24]. Governance fragmentation is manifested in the inconsistent interpretation of the same regulations by multiple jurisdictions, leading to repeated ethical reviews [25]. The separation of technology and law also leads to secondary compliance risks. Finally, the disparity in penalty intensity and the lack of cross-border accountability significantly inhibit sharing willingness, resulting in the termination of 37% of cross-border medical collaborations [26]. Breaking the deadlock requires a two-pronged approach: deep integration of regional legal coordination tools and Privacy-Enhancing Technologies (PETs), but the core lies in reconstructing a global governance framework to balance human rights protection and data flow.

Privacy and Security Risks

Firstly, the EU General Data Protection Regulation (GDPR) requires cross-border transmission to meet strict privacy standards, but laws in other countries conflict with this, making it difficult to implement mechanisms such as Standard Contractual Clauses (SCCs) and even forcing research to be suspended [27,28]. Secondly, medical institution systems are incompatible with each other, and data formats lack unified standards, leading to complex interoperability issues in cross-border sharing. Moreover, medical data is stored in different clouds, increasing the risk of data leakage and tampering [29,30]. In addition, significant differences in data protection regulations among countries and the lack of a unified regulatory framework have weakened public willingness to share due to concerns about data abuse [31]. At the same time, the decentralization of cloud storage obscures data sovereignty, further hindering collaboration [30]. Although solutions such as blockchain and homomorphic encryption can partially mitigate risks, they face problems such as imperfect consensus mechanisms, low computational efficiency, and lack of universally recognized technical standards [29,32]. Privacy-enhancing technologies still face challenges in balancing data utility and privacy [27].

Technical and Interoperability Barriers

The most concerning issue is that medical systems in various countries adopt heterogeneous data models, communication protocols, and storage formats, making data unable to be directly parsed or transmitted. Secondly, differences in data formats among European systems cause information compatibility issues, requiring complex mapping and conversion for basic exchange, significantly reducing efficiency and increasing error risks [33]. Meanwhile, incompatible communication protocols can cause data transmission delays or security vulnerabilities, affecting the timeliness of clinical decisions [34]. Additionally, the lack of unified medical terminology standards leads to ambiguities in key clinical concepts in cross-border scenarios, hindering accurate interpretation and integration of data. Even if international standards are adopted, their high implementation costs and difficulties in localized adaptation still limit practical applications [35,36]. At the same time, cross-border sharing relies on decentralized infrastructure, but existing systems are mostly based on isolated architectures and lack standardized interfaces. The fragmentation of technical infrastructure exposed in the advancement of the European Health Data Space (EHDS) requires coordination of data storage schemes and security protocols among different countries, while emerging technologies such as blockchain have not yet formed a widely recognized deployment framework [1,29,37].

Summary

There are fundamental differences in the definition, anonymization standards, and protection scope of health data among countries, forcing institutions to rely on inefficient Standard Contractual Clauses (SCCs). The adequacy assessment in the EU takes 3-6 months, and coupled with divergent interpretations of the same regulations by multiple jurisdictions, 37% of cross-border collaborations are terminated. Meanwhile, the high anonymization threshold of GDPR impairs the research utility of data, incompatibility of medical institution systems exacerbates data leakage risks, and decentralized cloud storage obscures data sovereignty. Public concerns about data abuse further inhibit willingness to share. Although technologies such as blockchain and homomorphic encryption can partially mitigate risks, they have low computational efficiency and lack unified standards. In addition, heterogeneous data models, communication protocols, and lack of medical terminology standards lead to data parsing difficulties, requiring complex mapping and conversion with high error rates. The high implementation costs and localized adaptation difficulties of international standards, as well as the lack of standardized interfaces in decentralized architectures, hinder the timeliness of clinical decisions.

Solutions to the Difficulties in Cross-border Medical Data Sharing

Solutions to Legal and Compliance Differences

Firstly, international agreement coordination is a basic path.

The EU clarifies the legality of special processing of health data through Article 9 of the GDPR and promotes mutual recognition of electronic prescriptions among member states [38]. Africa needs to establish standardized cross-border agreement templates to bridge differences in protection levels among countries [39,1]. Meanwhile, regional legal adaptation emphasizes the integration of ethics and systems. The Southern African Development Community (SADC) enhances trust by clarifying data usage conditions, dynamic consent mechanisms, and benefit distribution rules [1], while South Africa's POPIA Act recommends formulating codes of conduct to refine the responsibilities of data controllers [39]. Secondly, at the contractual and technical governance level, after the Schrems II case, supplementary measures are required to minimize and anonymize data and strengthen third-party certification. EU Standard Contractual Clauses (SCCs) need to specify storage time limits and audit mechanisms [40,41]. Finally, technology-driven solutions include using blockchain to establish a "data owner system" to realize individual data control and value returns [20], and developing ontology-based compliance audit models to automatically verify the legality of data sharing. These solutions balance public health needs and individual rights through the linkage of international organizations, regional alliances, and technical tools [1,42].

Solutions to Privacy and Security Risks

At the technical level, blockchain has become a core support due to its decentralized, tamper-proof, and traceable characteristics. For example, public chain technology can realize secure authentication, dynamic desensitization, and distributed auditing of cross-institutional data, and combined with homomorphic encryption, ensure confidentiality during data processing [43]. In terms of management mechanisms, it is necessary to establish a "people-oriented" protocol traceability system, solidify data ownership rules and cross-border transmission processes through smart contracts, and supplement with privacy impact assessments and Standard Contractual Clauses (SCCs) to clarify data minimization, storage periods, and legal obligations of recipients [44,20]. The cross-border nature requires enhanced technical guarantees such as third-party certification, and the construction of a full-cycle transparent management and control system covering pre-filing, in-process monitoring, and post-event accountability [45,20]. These collaborative strategies significantly reduce risks such as re-identification attacks, background knowledge leakage, and cross-border compliance conflicts while ensuring data availability.

Solutions to Technical and Interoperability Barriers

Notably, a hierarchical interoperability framework can systematically solve the docking problem of heterogeneous systems by enforcing clinical terminology standardization and universal data structures to achieve semantic unification [37]. Meanwhile, blockchain technology, with its decentralized and tamper-proof characteristics, combined with ciphertext-policy attribute-based encryption (CPABE) and symmetric encryption (AES) schemes, can ensure secure cross-border data transmission and support fine-grained access control and emergency authorization mechanisms, solving the contradiction between privacy and sharing. At the policy and governance level, the EU's TEHDAS joint action formulates technical specifications for cross-border data sharing and GDPR-compatible data governance models to coordinate legal differences among member states [46]. Studies have also shown that economic incentives alone cannot break through interoperability bottlenecks, and transnational collaboration mechanisms are needed to unify technical standards and optimize data sovereignty management processes [47]. In addition, systematic literature analysis emphasizes the need to balance technical solutions and organizational processes, such as redesigning cross-institutional workflows and clarifying data traceability rules to eliminate cultural and operational barriers [48]. In summary, breaking the dilemma of cross-border medical data sharing requires integrating technological innovation (blockchain + hierarchical interoperability framework), policy synergy (transnational legal adaptation), and organizational restructuring (business process standardization) to form a closed-loop governance system.

Summary

Solving the difficulties in cross-border medical data sharing requires multi-dimensional collaborative strategies: at the legal and compliance level, relying on international agreement coordination and regional legal adaptation to bridge differences, while strengthening contractual and technical governance; in the field of privacy and security, the decentralized and tamper-proof characteristics of blockchain technology combined with homomorphic encryption realize secure data transmission and dynamic desensitization, supplemented by smart contracts to solidify ownership rules and a full-cycle transparent management and control system, significantly reducing re-identification risks; technical and interoperability barriers are addressed by hierarchical frameworks enforcing clinical terminology standardization, and the EU's TEHDAS action unifying technical specifications, while blockchain combined with attribute-based encryption (CPABE) supports fine-grained access control, and transnational collaboration mechanisms are needed to optimize data sovereignty management. Finally, technological innovation (blockchain + interoperability framework), policy synergy (international agreements and regional legal adaptation), and organizational restructuring (business process standardization) form a closed loop to balance public health needs and individual rights.

Conclusions and Future Development

Cross-border medical data sharing has shown great value in

accelerating disease research, drug development, improving the accuracy of personalized medicine, and enhancing global public health emergency responses. However, its development faces severe challenges: legal and compliance differences make cross-border transmission complex and time-consuming; privacy and security risks weaken public trust; technical fragmentation and interoperability barriers seriously hinder the effective use of data. Looking to the future, breaking through the bottlenecks requires multi-dimensional collaborative strategies: at the legal level, bridging differences through international agreement coordination and regional legal adaptation; at the privacy and security level, using blockchain technology combined with attribute-based encryption and smart contracts to achieve dynamic desensitization, fine-grained access control, and ownership solidification, building a foundation of security and trust; at the technical and interoperability level, implementing hierarchical interoperability frameworks to enforce standardization, and unifying technical specifications through policy synergy. Long-term, a closed-loop governance system integrating technological innovation, policy synergy, and organizational restructuring will significantly improve interoperability and trust, ultimately promoting cross-border sharing to become a core driver of global medical progress and health equity.

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