Chapter

Perspective Chapter: Integrating Large Language Models and Blockchain in Telemedicine

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Abstract

This perspective paper examines how combining artificial intelligence in the form of large language models (LLMs) with blockchain technology can potentially solve ongoing issues in telemedicine, such as personalized care, system integration, and secure patient data sharing. The strategic integration of LLMs for swift medical data analysis and decentralized blockchain ledgers for secure data exchange across organizations could establish a vital learning loop essential for advanced telemedicine. Although the value of combining LLMs with blockchain technology has been demonstrated in non-healthcare fields, wider adoption in medicine requires careful attention to reliability, safety measures, and prioritizing access to ensure ethical use for enhancing patient outcomes. The perspective article posits that a thoughtful convergence could facilitate comprehensive improvements in telemedicine, including automated triage, improved subspecialist access to records, coordinated interventions, readily available diagnostic test results, and secure remote patient monitoring. This article looks at the latest uses of LLMs and blockchain in telemedicine, explores potential synergies, discusses risks and how to manage them, and suggests ways to use these technologies responsibly to improve care quality.

Keywords: telemedicine, artificial intelligence, large language models, blockchain, interoperability, data privacy, technology convergence

1. Introduction

The practice of telemedicine has accelerated rapidly, with virtual visits growing 38-fold since the start of the COVID-19 pandemic [1]. This massive expansion increased access and convenience for patients consulting remotely with physicians and other healthcare providers [2]. However, fundamental challenges remain in delivering personalized, integrated care. Practitioners face constrained time, administrative support, and technological skills [3]. Patients struggle to coordinate across disconnected providers, lacking holistic records [4]. Despite profound progress, telemedicine still remains more promise than fulfillment.

Emerging technologies like artificial intelligence (AI) and blockchain present important solutions. Natural language processing AI in the form of large language

Feature	Description	Capabilities	Examples
LLMs	Large neural networks are trained on massive amounts of text data to understand and generate human-like text.	Assisting in diagnostic processes, generating patient information, and automating administrative tasks.	ChatGPT, Anthropic, diagnostic tools, and chatbots for patient engagement
Blockchain	A decentralized digital ledger that records transactions across many computers so that the record cannot be altered retroactively.	Interoperability across healthcare systems, secure encryption of patient records, and data immutability. Patients own and control their own medical data.	Bitcoin, Ethereum, Cardano, Hyperledger Fabric
Overlap	Combines LLMs knowledge processing with blockchain's secure, decentralized data management.	Improved patient management while allowing patients to securely control and share their own medical data.	LLM integration into the Cardano blockchain

Table 1.
Synergy of LLMs with blockchain in medicine.

models (LLMs) can supply physicians with contextualized recommendations from an ever-expanding range of journals and cases [5]. Blockchain facilitates decentralized knowledge-sharing across distance and medical specialties [6]. While neither of these newer technologies is a silver bullet, converged together LLMs and blockchain enable improved overall medical care across scattered systems.

This perspective article explores intersecting applications of technology, specifically LLMs and blockchain, propelling the next generation of telemedicine. While drawing upon existing literature to provide context, the main focus is on proposing a novel perspective on how the integration of these technologies can transform telemedicine. The article argues that the synergistic combination of LLMs and blockchain has the potential to address key challenges in telemedicine, such as care personalization, system integration, and patient data privacy/sharing. Opportunities to augment physicians' abilities to diagnose, monitor, and engage patients remotely are reviewed (**Table 1**). Meaningful successes from early adoption are evaluated in light of enduring risks requiring mitigation before mainstream adoption.

Leading medical innovations will combine patient-centered care with advanced technologies. Blockchain technologies can help achieve that by securely transmitting diagnostics and increasing interoperability between electronic health records [7]. LLM-based AI assistants can intelligently adjust guidance based on holistic health records and patient communication [8]. Telemedicine empowered by LLMs and blockchain will potentially expand access to care, decrease costs, and improve community health. While significant challenges exist, this perspective article argues that the next frontier of telemedicine lies in the convergence of these technologies.

2. Literature review

No articles that addressed the specific issue of combining LLMs with blockchain technology in telemedicine could be identified. Therefore, a literature review was performed to provide a foundational logic for the proposal of combining LLMs with blockchain technology in telemedicine. By examining relevant literature on the individual components of LLMs and blockchain technology and their pairwise relationships, this focused review aims to demonstrate the potential for integrating these technologies to enhance telemedicine. A targeted literature search using PubMed and Google Scholar was performed to inform this perspective on integrating LLMs and blockchain in telemedicine.

Recent studies have explored the applications of LLMs in healthcare, highlighting their potential to assist with tasks such as clinical decision support, patient triage, and documentation [9]. They suggest that LLMs can help streamline processes and improve efficiency in healthcare settings. However, data privacy, bias, and reliability challenges have also been noted, underscoring the need for careful implementation and monitoring [10].

Blockchain technology has been investigated for its potential to enhance healthcare security, privacy, and interoperability [11]. Blockchain-based systems have been proposed to manage electronic health records, enable secure data sharing, and facilitate patient consent management [12]. While these applications show promise, scalability, regulatory compliance, and user adoption challenges remain significant [7].

Although the literature on the specific combination of LLMs and blockchain in healthcare is scarce, there is recognition that combining LLMs with blockchain technology can improve data privacy in other fields [13]. Also, Sam Altman, the CEO of OpenAI, and the Cardano blockchain recently have engaged in talks looking into putting an LLM on its distributed network. Since current LLMs are centralized and controlled by a single entity, there are concerns regarding data privacy, bias, and censorship. A decentralized blockchain-based LLM would increase the transparency of LLMs, potentially improving diversity and decreasing costs to the end-user [14].

Telemedicine has been widely studied, with numerous articles discussing its benefits, challenges, and future directions. Key challenges identified in the literature include data security, privacy, licensure, and integration with existing healthcare systems [15]. As telemedicine continues to evolve, researchers have emphasized the need for innovative solutions to address these challenges and improve patient outcomes [16].

A recent literature review provides a complementary overview of key aspects of eHealth systems, including architectures, mHealth advances, and security challenges, that aligns with and reinforces many of the topics discussed in this manuscript [17]. The authors delve into the technical implementation of blockchain, IoT, and cloud-based architectures, detailing, for example, a three-layer IoT architecture consisting of device, network, and application layers. Their discussion of mHealth advances covers wireless sensors, mobile devices, and short-range, satellite, and cellular communication technologies, including the evolution from 3G to 5G networks. Common security threats outlined, such as eavesdropping, data modification, and denial of service attacks, echo the security challenges highlighted in this work. The research challenges identified, spanning areas like standardization, communication speed, blockchain limitations, and mHealth literacy, intersect with and could further inform the key research gaps and future directions presented herein. Collectively, the survey offers some additional context and examples that enrich the core concepts while pointing to the same overarching opportunities and need for continued research and development to realize the full potential of eHealth systems.

By synthesizing insights from these separate bodies of literature, a foundation for this perspective is given on the potential benefits and challenges of integrating LLMs and blockchain in telemedicine. While the specific combination of these technologies in telemedicine has not been extensively studied, the existing literature on their individual applications and pairwise relationships suggests that their integration could offer novel solutions to enhance security, privacy, and decision support in telemedicine. By exploring possible synergies, this perspective article aims to contribute to the ongoing discussion on the future of telemedicine and the role of emerging technologies in transforming healthcare delivery.

3. Large language models in telemedicine

Large language models (LLMs) are a class of AI systems that can analyze, comprehend, and generate content after training on massive amounts of data [18]. Current LLMs are estimated to have over 175 billion parameters training on over 1 trillion words across textbooks, Wikipedia articles, and other digital content [19]. These LLMs utilize neural networks structured in "transformer" architectures, which continue learning through weights and transformations on input [20]. These interconnected nodes enable the rapid interpretation of patterns across extremely large datasets that are not approachable manually. LLMs can recognize relationships and generate natural language responses by absorbing tremendous volumes of information. These LLMs are continually updated by curating training data and integrating feedback from human users to create safety guardrails.

For telemedicine applications, customized LLMs trained on clinical sources can quickly analyze guidelines that synthesize connections in patient charts. The continued maturation of LLMs could potentially enable immediate access to current guidelines at the point of care, revolutionizing telemedicine practice by increasing the speed of informed decision-making. LLMs can also highlight a patient's important and relevant medical background [21]. For instance, an LLM may review patient history and symptoms pre-visit. It would then supply background on aligned conditions ahead of the telemedicine visit with the clinician. Then, during a live consultation, the LLM could cross-check emerging details against a highly curated medical training database. This would prompt physicians with validated recommendations specific to that patient in real-time dialog. LLMs have demonstrated abilities to assist with rapid chart reviews. This capacity to quickly perform a record review and present relevant information and perhaps previously unknown connections or patterns to the clinician presents a major advance in computer technology.

Currently, startups worldwide are actively working to tailor and validate AI usage for telemedicine screening, diagnosis, and care support. Applications are broad, from radiology image evaluation [22] to patient chart reviews [23]. AI, using LLMs, could be integrated into all aspects of the televisit, even including a real-time evaluation of the conversation [24].

However, concerns exist about the use of LLMs in medicine, including their tendency to generate unreliable responses [25]. This can be partly due to randomness parameters, crucial for creating varied and fluent language, but can also introduce uncertainty when analyzing critical medical data. The result is that the analysis of clinical data may not be routinely uniform but will contain inconsistent and unreliable responses inappropriate for clinical practice [26]. While randomness offers benefits like adaptability for generating possible diagnoses, it's essential to consider other factors, such as biases in training data and poorly constructed prompts.

While LLMs incorporate a large amount of knowledge by training on a huge amount of data, this unsupervised learning model can also result in harmful gender and racial biases [27]. These biases can be demographic, reflecting societal inequalities present in the training data, or algorithmic, stemming from how the training algorithms process information. For example, an LLM might underdiagnose certain demographics due to historical data underrepresentation or suggest biased treatment options influenced by algorithmic limitations. Recognizing and mitigating these biases through strategies like diversifying training data, employing fairness-aware algorithms, and ongoing human review is essential for responsible integration into telemedicine.

Another concern about the introduction of AI into telemedicine is medical malpractice. If an AI makes a mistake, will the AI or the human clinician be responsible? Alternatively, if the clinician made a mistake but had consulted an AI at the time of the patient visit, would that decrease their liability [28]? The legal landscape is complex and rapidly evolving. Currently, the recommendation is for clinicians to use LLMs only as assistive or confirmatory tools [29].

Finally, in addition to the concerns about accuracy, reliability, and malpractice, there is great concern regarding the ability of LLMs to maintain patient privacy [30]. Although utilizing locally deployed LLMs instead of a centralized LLM may help maintain privacy [31], anonymization and data encryption remain crucial. There remains concern that online tools are highly insecure and that these LLMs can leak secrets [32, 33].

While material risks exist surrounding validation and responsibility, when applied judiciously, LLMs may meaningfully assist physicians practicing telemedicine. The continued maturation of LLMs could enable immediate access to current guidelines at the point of care. Realizing that potential depends on a disciplined assessment of outcomes from initial implementations rather than speculation. Further refinement must shape their evolving role in supporting compassionate, safe, and high-quality virtual care delivery.

4. Improving security with blockchain technology

Blockchains are distributed ledgers that enable secure, transparent record-keeping without a central authority that can tamper with or modify the data. These distributed ledgers are databases shared across multiple computers. Blockchains can be public and globally distributed, as is the case for cryptocurrencies such as Bitcoin and smart contract platforms such as Ethereum. Private, permissioned blockchains are also common. These blockchains, such as the Hyperledger Fabric framework, only allow approved members to join [34]. Multiple decentralized nodes operate blockchain, while cryptographic techniques secure and verify information.

4.1 Understanding blockchains and distributed ledgers

Blockchains store records across computer networks. A public shared ledger synchronizes data instead of having the data siloed in a proprietary system owned by a healthcare network. Blockchain cryptography secures the distributed database. This high level of security is obvious when noting that the Bitcoin blockchain, with a market capitalization of over $800B available to hackers, has not suffered a breach since its creation in 2009. Although individual wallets and exchanges are vulnerable, the blockchain network itself has remained intact [35].

When users approve transactions like adding records through pre-agreed consensus protocols, blockchains permanently and immutably log those exchanges across a large decentralized network using digital signatures. The consensus protocols ensure all nodes validate new data additions prior to appending the shared database. This establishes a verifiable audit trail, building trust without the vulnerability of intermediaries introducing corruption.

4.2 Healthcare blockchain adoption

In telemedicine, blockchain shows early promise in improving:

- *Security*—permissioned blockchains in healthcare often use private keys like digital passports for secure data encryption and access control. This is an improvement to siloed systems where records are isolated, and securing sharing across institutions is extremely challenging. Only authorized healthcare professionals who have been granted these keys can enter the network and access/update patient records. Without the correct keys, unauthorized parties cannot decrypt data or tamper with information, preventing breaches. Patients, not healthcare providers, insurance companies, or hospitals, control their own keys and, therefore, fully control their personal data.

- *Interoperability*—by consolidating records, shared ledgers can integrate diagnostics across otherwise siloed health systems during care coordination. For example, hospitals today struggle to share lab tests and imaging across different provider networks or medical record platforms. This causes delays, repeat testing, and disconnected care. Blockchain-based ledgers could allow seamless, cross-affiliate sharing of full patient diagnostic history, enabling streamlined specialist consultations, transfers, and treatment continuity.

- *Privacy*—zero-knowledge proofs applied to patient records could allow patients to share specific medical information without revealing their full identity. For example, a patient could prove they have a certain gene variation for research purposes without disclosing their name or other personal details. This privacy goes well beyond research. Blockchain also empowers patients to keep their data private through decentralized storage, pseudonymization, and fine-grained access control, allowing secure sharing with auditability.

Blockchain systems could secure telemedicine data by leveraging decentralized identity standards that provide authentication for individuals, organizations, and connected devices. Digital keys enacted through secure multi-party computation and zero-knowledge proof schemes serve as dynamically verifiable credentials with finely tuned permissions. This allows identity owners to selectively disclose claims required to authorize health data exchange. For instance, a patient could authorize the transmission of diagnostic results to a new specialist by presenting a temporary access credential registered on-chain without revealing unrelated sensitive details. Health networks interfacing with these blockchain frameworks ensure accountability as data requests and permissions are immutably recorded in auditable distributed ledgers. Such identity data marketplaces can balance utility with privacy, allowing patients sovereignty over sharing levels.

4.3 Ongoing opportunities and risk management

As blockchain sees rising adoption in healthcare contexts, maintaining rigorous security, privacy, and interoperability standards is required for responsible scaling of these technologies. Innovations like hardening smart contract code, strengthening consensus protocols to prevent manipulation risks, and advancing encryption techniques resistant to quantum computers will help distributed ledger solutions secure telemedicine care models in the future. While talent shortages in software engineering and the difficulty of integrating legacy systems will need to be overcome, continued progress in blockchain-specific healthcare infrastructure points towards a coming coalescence capable of safely streamlining telemedicine data sharing worldwide. And society has already made tremendous strides. For example, the successful use of blockchain technology in securing medical records dates back to at least 2016, when Estonia began securing its health records [36]. Estonia's successful use of blockchain technology in securing medical records demonstrates the potential for this technology to transform data security in telemedicine. Supporting this promising beginning, analysts project the adoption of blockchain in healthcare is expected to grow significantly by 2030, with a compound annual growth rate of around 40% [37].

5. Opportunities and risks of AI and blockchain in telemedicine

When applied judiciously, integrating AI in the form of LLMs with blockchain technology into telemedicine infrastructure presents noteworthy opportunities to improve care outcomes as well as inherent risks requiring mitigation.

5.1 Opportunities

Integrating blockchain with LLMs poses meaningful opportunities to improve the speed and accuracy of evaluating patient records and improving management. Several key opportunities are associated with thoughtfully incorporating these technologies:

- *Visit efficiency*: LLMs could enhance virtual visit efficiency by rapidly summarizing the pertinent medical history and flagging relevant past conditions ahead of teleconsultations. LLMs excel at rapidly summarizing large volumes of data.

- *Quality control*: LLMs could help improve patient visit consistency by monitoring dialog in real-time and summarizing validated recommendations.

- *Improved triage*: LLM-based chatbots could allow increased throughput of common complaints via automated triaging. Increased speed of appropriate referrals would expand access to care.

- *Better security*: LLMs have an unproven track record in ensuring patient privacy, but combining LLMs with blockchain technology could mitigate these concerns. A blockchain-LLM system could improve security and patient privacy compared to existing systems. Record archiving would be more secure, more private, and immutable.

- *Interoperability*: blockchain technology cuts across geopolitical boundaries, allowing improved data sharing globally.

5.2 Risks

Prudent adoption necessitates actively addressing salient risks of new and advanced technologies, including:

- *Bias*: LLMs are known to be vulnerable to bias and have demonstrated inequitable performance across patient demographics.

- *Unclear responsibility*: malpractice issues remain murky when technology breaks down or provides inaccurate information.

- *Privacy violations*: the inappropriate use of LLMs or programming errors could potentially result in privacy breaches.

- *Integration*: overcoming legacy infrastructure fragmentation will be challenging. Knowledge gaps in the technology development workforce remain significant. A coordinated global effort at establishing interoperability standards could help improve development.

Integrating blockchain with LLMs poses meaningful opportunities to improve the speed and accuracy of evaluating patient records and improving management. When combined with blockchain's security features and interoperability, LLMs have great potential to advance quality, increase patient privacy, decrease costs, and increase access to care.

However, significant challenges exist. Fragmentation, legacy systems, and talent gaps hinder progress [38]. Privacy concerns pose another significant risk when integrating blockchain and LLMs into telemedicine systems. While blockchain provides initial data privacy through encryption and pseudonymity, it remains vulnerable to privacy leakage if sufficient patient information is linked. Privacy-preserving mechanisms can be deployed in conjunction with blockchain technology to address these issues. These include advanced encryption schemes like attribute-based encryption, which ensures fine-grained access control by associating attributes with private keys, and proxy re-encryption, which enables secure data sharing without revealing private keys. Additionally, techniques such as zero-knowledge proofs and homomorphic encryption can further enhance privacy by allowing computation on encrypted data without revealing the underlying information. Smart contracts can also be leveraged to enforce data access control policies and maintain an immutable audit trail. Careful integration of these privacy mechanisms is crucial to realize the full potential of blockchain in enabling secure, privacy-preserving telemedicine systems while mitigating the associated risks [39]. By complementing the contextual analysis capabilities of LLMs with the secure data management afforded by privacy-enhanced blockchain solutions, telemedicine platforms can deliver more personalized and privacy-centric care.

Ethical accountability must be ingrained at every stage of convergence. Safeguarding patient interests must remain the top priority. This demands moving forward with advanced technologies but with a balance of caution, ensuring safe implementation. LLMs and blockchain technologies provide this balance of innovation with safety.

5.3 Regional differences in challenges and barriers

Integrating LLMs and blockchain in telemedicine faces challenges and barriers across different regions. In Europe and the US, data privacy regulations such as the General Data Protection Regulation (GDPR) and the Health Insurance Portability and Accountability Act (HIPAA) pose strict yet slightly different requirements for handling sensitive patient data [40]. Ensuring compliance with these regulations while implementing new technologies can be complex and time-consuming [41].

In Asia, the digital divide between urban and rural areas presents a significant challenge to the widespread adoption of telemedicine [42]. Financial costs and limited access to reliable internet connectivity and digital devices in some regions may hinder the implementation of AI and blockchain solutions. Additionally, cultural differences in healthcare decision-making and patient-provider relationships may influence the acceptance of these technologies [43].

The Middle East faces its own set of challenges, including a lack of standardized electronic health record systems and limited interoperability between healthcare providers [44]. This fragmentation and lack of infrastructure can make it difficult to integrate new technologies seamlessly [45].

Despite these regional differences, there are also common barriers that transcend geographical boundaries. These include concerns about data security and privacy, the need for robust regulatory frameworks, and the requirement for healthcare professionals to adapt to new technologies and workflows. Addressing these shared challenges will be crucial for the successful integration of LLMs and blockchain in telemedicine across all regions.

6. Research applications

For research, the true transformative power of this synergy lies in combining advanced LLMs' ability to rapidly evaluate large amounts of data with blockchain's ability to securely share medical information [13]. Furthermore, this convergence of technologies creates the ability to implement a continuous learning loop with potential major, tangible benefits such as:

- Patient data (wearables, tests, records) is shared via blockchain's distributed ledgers, allowing patients to control their private information while enabling anonymous sharing with researchers.

- Shared data then trains advanced LLMs to provide personalized guidance, augment diagnostics, coordinate interventions, and update patient records.

Early adopters have already demonstrated this powerful synergy between LLMs and blockchain technology. For example, Cardano, a public blockchain platform, is working to develop a decentralized LLM integrated into their blockchain. This pioneering initiative addresses pressing data privacy, fairness, and bias issues [46]. The integration of AI with blockchain technology in cardiovascular medicine has been pursued due to the combination of AI's analytic capabilities with blockchain's secure management of data [47]. The resulting data marketplace could empower patients with more control over their personal medical information, from wearables to lab tests, health records, and medical images. Patients could then voluntarily share anonymized data to help researchers access vast, diverse datasets, leading to improved diagnostic and treatment recommendations. This helps mitigate risks of bias inherent in limited institutional data silos.

7. Discussion

The perspective presented in this article has important implications for the future of telemedicine. By integrating LLMs and blockchain technology, key challenges related to care personalization, system integration, and patient data privacy/sharing can be addressed. The synergistic combination of these technologies has the potential to transform telemedicine by improving diagnostics, coordinating interventions, and creating more personalized medical care.

Real-world pilots combining LLMs and blockchain in telemedicine are currently in the theoretical stage only. However, they will require deliberative caution while evaluating their impact and building physician trust. While the potential exists, priority areas remain around integrating systems, enabling secure data sharing, and providing versatile clinical tools. A global effort at setting standards could greatly assist the development of these technologies.

Global interest in digital health has recently declined after reaching an all-time high investment funding of $59.7B in 2021. In 2022, global digital health funding fell to $25.9B; in 2023, it fell to $13.2B [48, 49]. Momentum continues around narrow, siloed point solutions rather than deeply integrated platforms that can address global issues such as improved access and healthcare equity.

Advancing interoperability frameworks is vital to lower proprietary barriers impeding unified data integration across closed vendor systems. Decentralized data sharing securely at scale requires collaboration to simplify integration burdens through co-designing open APIs and standards. This smoothes connections so physicians can access seamlessly combinable tools, not isolated platforms needing custom interfaces.

Additionally, emerging complementary technologies like extended reality and quantum computing could accelerate personalized interventions combined with AI and blockchain. For example, distributed mentor networks leveraging VR case reviews informed by LLM guidance tracked on blockchain ledgers may enhance clinical learning that can scale globally. Quantum machine learning pattern recognition applied to multi-layer de-identified datasets could also unlock optimal treatment insights. Rather than converging into narrow siloes, transformative progress builds upward through expanding technology synergies centered on patient outcomes globally.

Ultimately, advancement depends on ethical governance, demonstrating consistent improvements to earn trust. Mathematical assurances around algorithmic behaviors must take priority over superficial marketing gestures. Transparency measures on alignment with clinical values, explanatory modes, bias elimination, and advisory monitoring will help anchor possibilities in accountability along with deliberate, patient-focused progress [50].

Moreover, the implementation of these technologies will require collaboration across disciplines and stakeholders, including healthcare providers, technology developers, policymakers, and patient advocates. Establishing clear guidelines and standards for the responsible development and deployment of these technologies will be critical to ensuring their safe and effective use in telemedicine.

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The path ahead holds no shortage of collaborative milestones if rooted in expanding access for all people - not merely increasing market share. Realizing the convergence where AI and blockchain enhance telemedicine depends on enlisting diverse expertise to scrutinize limitations courageously while accelerating discoveries proven to uplift universal care quality. This conscious effort could launch platforms enabling augmented diagnostics, orchestrated interventions, and democratized personalized guidance. These ingredients supporting modern telemedicine's next evolution exist through the ethical application of technology.

8. Conclusions

The convergence of LLMs, blockchain technology, and telemedicine holds vast potential; however, its responsible realization hinges significantly on adopting a patient-centric approach. Customized AI tools, such as LLMs, offer the capability to assist and potentially enhance human decision-making by enabling a swifter and more comprehensive analysis of patient records than manual review permits. Blockchains and distributed ledgers enable permission-based data fluidity, ensuring the utmost privacy and security of medical records, accessible globally only to individuals authorized by the patient. Telemedicine extends virtual access and provides uninterrupted healthcare services, regardless of geographical constraints.

By insisting on the highest standards to ensure global development, this synergy between LLMs and blockchain technologies has the potential to facilitate comprehensive advancements, including secure remote patient monitoring, decentralized storage and access to diagnostics, and real-time personalized guidance tailored to individual needs. These capabilities can lead to a reduction in errors, an expansion of human medical expertise, and the confident triaging of cases. However, without governance that prioritizes consistency, explainability, and transparency to establish trust, this promising synergy of technologies will fail to live up to its potential.

In conclusion, the perspective presented here argues that the convergence of LLMs, blockchain technology, and telemedicine holds vast potential for transforming telemedicine. The essential ingredients for this important convergence are within reach. Ultimately, the success of this convergence will depend on our willingness to embrace new advances while simultaneously advancing safety guardrails and prioritizing patient interests. By doing so, we can unlock the full potential of LLMs and blockchain in telemedicine and create a more equitable, accessible, and effective global healthcare system.

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References

[1] Bestsennyy O, Gilbert G, Harris A, Rost J. Telehealth: A post-COVID-19 reality? [Internet]. McKinsey. 2021. Available from: https://www.mckinsey.com/industries/healthcare/our-insights/telehealth-a-quarter-trillion-dollar-post-covid-19-reality

[2] Gajarawala SN, Pelkowski JN. Telehealth benefits and barriers. The Journal for Nurse Practitioners. 2021;**17**(2):218-221. DOI: 10.1016/j.nurpra.2020.09.013

[3] Nene S, Rauch M, Belanger D, Bennett R, Berry G, Saad N, et al. Personalized telehealth: Redesigning complex care delivery for the 65+ during the COVID pandemic: A survey of patients, caregivers, and health-care providers. Canadian Geriatrics Journal. 2023;**26**(1):150-175. DOI: 10.5770/cgj.26.641

[4] Lai YF, Lum AYW, Ho ETL, Lim YW. Patient-provider disconnect: A qualitative exploration of understanding and perceptions to care integration. PLoS One. 2017;**12**(10):e0187372. DOI: 10.1371/journal.pone.0187372

[5] Yang X, Chen A, PourNejatian N, Shin HC, Smith KE, Parisien C, et al. A large language model for electronic health records. npj Digital Med. 2022;**5**(1):194. DOI: 10.1038/s41746-022-00742-2

[6] Elangovan D, Long CS, Bakrin FS, Tan CS, Goh KW, Yeoh SF, et al. The use of blockchain technology in the health care sector: Systematic review. JMIR Medical Informatics. 2022;**10**(1):e17278. DOI: 10.2196/17278

[7] Schmeelk S, Kanabar M, Peterson K, Pathak J. Electronic health records and blockchain interoperability requirements: A scoping review. JAMIA Open. 2022;**5**(3):ooac068. DOI: 10.1093/jamiaopen/ooac068

[8] Nawab K, Ramsey G, Schreiber R. Natural language processing to extract meaningful information from patient experience feedback. Applied Clinical Informatics. 2020;**11**(2):242-252. DOI: 10.1055/s-0040-1708049

[9] Karabacak M, Margetis K. Embracing large language models for medical applications: Opportunities and challenges. Cureus. 2023;**15**(5):e39305. DOI: 10.7759/cureus.39305

[10] Jeyaraman M, Balaji S, Jeyaraman N, Yadav S. Unraveling the ethical enigma: Artificial intelligence in healthcare. Cureus. 2023;**15**(8):e43262. DOI: 10.7759/cureus.43262

[11] Taherdoost H. Privacy and security of blockchain in healthcare: Applications, challenges, and future perspectives. Sci. 2023;**5**(4):41. DOI: 10.3390/sci5040041

[12] Kiania K, Jameii SM, Rahmani AM. Blockchain-based privacy and security preserving in electronic health: A systematic review. Multimedia Tools and Applications. 2023;**82**(18):28493-28519. DOI: 10.1007/s11042-023-14488-w

[13] Rizvi S. Blockchain-based LLMs: A game changer for data privacy protection [Internet]. Dataversity. 2023. Available from: https://www.dataversity.net/blockchain-based-llms-a-game-changer-for-data-privacy-protection/

[14] Decentralized Large Language Model: Cardano and Altman Join Forces [Internet]. HyScaler. 2023. Available from: https://hyscaler.com/insights/large-language-model-cardano-altman/

[15] Linkous J. Challenges in telehealth. In: Board on Health Care Services, Institute of Medicine, editors. The Role of Telehealth in an Evolving Health Care Environment: Workshop Summary. Washington (DC): National Academies Press (US); 2012. pp. 17-19. DOI: 10.17226/13466

[16] Haleem A, Javaid M, Singh RP, Suman R. Telemedicine for healthcare: Capabilities, features, barriers, and applications. Sensors International. 2021;**2**:100117. DOI: 10.1016/j.sintl.2021.100117

[17] Alenoghena CO, Onumanyi AJ, Ohize HO, Adejo AO, Oligbi M, Ali SI, et al. eHealth: A survey of architectures, developments in mHealth, security concerns and solutions. International Journal of Environmental Research and Public Health. 2022;**19**(20):13071. DOI: 10.3390/ijerph192013071

[18] Birhane A, Kasirzadeh A, Leslie D, Wachter S. Science in the age of large language models. Nature Reviews Physics. 2023;**5**(5):277-280. DOI: 10.1038/s42254-023-00581-4

[19] Brown TB, Mann B, Ryder N, et al. Language models are few-shot learners. arXiv. 2020;**2005**:14165v4. DOI: 10.48550/arxiv.2005.14165

[20] Toews R. Transformers Revolutionized AI. What Will Replace Them? [Internet]. Forbes. 2023. Available from: https://www.forbes.com/sites/robtoews/2023/09/03/transformers-revolutionized-ai-what-will-replace-them/?sh=7280a52b9c1f

[21] Meskó B. The impact of multimodal large language models on health care's future. Journal of Medical Internet Research. 2023;**25**:e52865. DOI: 10.2196/52865

[22] Winkel DJ, Heye T, Weikert TJ, Boll DT, Stieltjes B. Evaluation of an AI-based detection software for acute findings in abdominal computed tomography scans: Toward an automated work list prioritization of routine CT examinations. Investigative Radiology. 2019;**54**(1):55-59. DOI: 10.1097/RLI.0000000000000509

[23] Ge J, Li M, Delk MB, Lai JC. A comparison of a large language model vs manual chart review for the extraction of data elements from the electronic health record. Gastroenterology. 2024;**166**(4):707-709.e3. DOI:10.1053/j.gastro.2023.12.019

[24] Zoom. Zoom Debuts New AI Companion Capability for Whiteboard, Expands Availability to Industries [Internet]. 2023. Available from https://news.zoom.us/ai-companion-zoomtopia/ [Accessed: January 30, 2024]

[25] Currie GM. Academic integrity and artificial intelligence: Is ChatGPT hype, hero or heresy? Seminars in Nuclear Medicine. 2023;**53**(5):719-730. DOI: 10.1053/j.semnuclmed.2023.04.008

[26] Heston TF, Lewis LM. ChatGPT provides inconsistent risk-stratification of patients with atraumatic chest pain. medRxiv. 2023;**11**(29):23299214. DOI: 10.1101/2023.11.29.23299214

[27] Zack T, Lehman E, Suzgun M, Rodriguez JA, Celi LA, Gichoya J, et al. Assessing the potential of GPT-4 to perpetuate racial and gender biases in health care: A model evaluation study. Lancet Digital Health. 2024;**6**(1):e12-e22. DOI: 10.1016/S2589-7500(23)00225-X

[28] Schweikart SJ. Who will be liable for medical malpractice in the future? How the use of artificial intelligence in medicine will shape medical tort law. Minnesota

Journal of Law, Science & Technology. 2021;**22**:1

[29] Banja JD, Hollstein RD, Bruno MA. When artificial intelligence models surpass physician performance: Medical malpractice liability in an era of advanced artificial intelligence. Journal of the American College of Radiology. 2022;**19**(7):816-820. DOI: 10.1016/j.jacr.2021.11.014

[30] Blease C. Open AI meets open notes: Surveillance capitalism, patient privacy and online record access. Journal of Medical Ethics. 2024;**50**(2):84-89. DOI: 10.1136/jme-2023-109574

[31] Cai W. Feasibility and prospect of privacy-preserving large language models in radiology. Radiology. 2023;**309**(1):e232335. DOI: 10.1148/radiol.232335

[32] Yu J, Wu Y, Shu D, Jin M, Xing X. Assessing prompt injection risks in 200+ custom GPTs. arXiv. 2023;2311.11538v1. DOI: 10.48550/arXiv.2311.11538

[33] Burgess M. OpenAI's custom chatbots are leaking their secrets [Internet]. Wired. 2023. Available from: https://www.wired.com/story/openai-custom-chatbots-gpts-prompt-injection-attacks/

[34] Androulaki E, Manevich Y, Muralidharan S, Murthy C, Nguyen B, Sethi M, et al. Hyperledger fabric: A distributed operating system for permissioned blockchains. In: Proceedings of the Thirteenth EuroSys Conference on - EuroSys '18. New York, New York, USA: ACM Press; 2018. pp. 1-15. DOI: 10.1145/3190508.3190538

[35] Sterling A. Can bitcoin network Be hacked? The safety of cryptocurrency [Internet]. Doubloin. 2023. Available from: https://www.doubloin.com/learn/can-bitcoin-network-be-hacked

[36] Heston TF. A case study in blockchain health care innovation. International Journal of Current Research. 2017;**9**(11):60587-60588

[37] Blockchain technology in healthcare market projected to reach USD 14.1 billion by 2030 [Internet]. Global Newswire. 2023. Available from: https://www.globenewswire.com/en/news-release/2023/11/30/2788314/0/en/Blockchain-Technology-in-Healthcare-Market-projected-to-reach-USD-14-1-Billion-by-2030-growing-at-a-CAGR-of-37-5-during-the-forecast-period-of-2023-2030-pronounced-by-MarketDigits-.html

[38] AbdelSalam FM. Blockchain revolutionizing healthcare industry: A systematic review of blockchain technology benefits and threats. Perspectives in Health Information Management. 2023;**20**(3):1b

[39] Hiwale M, Walambe R, Potdar V, Kotecha K. A systematic review of privacy-preserving methods deployed with blockchain and federated learning for the telemedicine. Healthcare Analytics (New York, N.Y.). 2023;**3**:100192. DOI: 10.1016/j.health.2023.100192

[40] HIPAA vs. GDPR compliance: What's the difference? [internet]. OneTrust. 2022. Available from: https://www.onetrust.com/blog/hipaa-vs-gdpr-compliance/

[41] Polsinelli PC. GDPR Implementation and HIPAA Compliance: An Analysis of the GDPR and HIPAA for U.S. Health & Life Sciences Organizations [Microsoft White paper]. 2018

[42] Wang X, Shi J, Lee KM. The digital divide and seeking health information on smartphones in Asia: Survey study of ten countries. Journal of Medical

Internet Research. 2022;**24**(1):e24086. DOI: 10.2196/24086

[43] Saha S, Beach MC, Cooper LA. Patient centeredness, cultural competence and healthcare quality. Journal of the National Medical Association. 2008;**100**(11):1275-1285. DOI: 10.1016/S0027-9684(15)31505-4

[44] Al-Samarraie H, Ghazal S, Alzahrani AI, Moody L. Telemedicine in middle eastern countries: Progress, barriers, and policy recommendations. International Journal of Medical Informatics. 2020;**141**:104232. DOI: 10.1016/j.ijmedinf.2020.104232

[45] Parkes P, Pillay TD, Bdaiwi Y, Simpson R, Almoshmosh N, Murad L, et al. Telemedicine interventions in six conflict-affected countries in the WHO eastern Mediterranean region: A systematic review. Conflict and Health. 2022;**16**(1):64. DOI: 10.1186/s13031-022-00493-7

[46] LLM integration unleashes AI advancements: 5 remarkable breakthroughs [Internet]. Hyscaler. 2023. Available from: https://hyscaler.com/insights/llm-integration-advancing-ai/

[47] Krittanawong C, Aydar M, Hassan Virk HU, Kumar A, Kaplin S, Guimaraes L, et al. Artificial intelligence-powered blockchains for cardiovascular medicine. The Canadian Journal of Cardiology. 2022;**38**(2):185-195. DOI: 10.1016/j.cjca.2021.11.011

[48] Diaz N. Digital health funding hits a wall [Internet]. Becker's Hospital Review. 2024. Available from: https://www.beckershospitalreview.com/digital-health/digital-health-funding-hits-a-wall.html

[49] State of digital health 2022 report [Internet]. CB Insights. 2023. Available from: https://www.cbinsights.com/research/report/digital-health-trends-2022/

[50] Sharma S, Rawal R, Shah D. Addressing the challenges of AI-based telemedicine: Best practices and lessons learned. Journal of Education Health Promotion. 2023;**12**:338. DOI: 10.4103/jehp.jehp_402_23