Generative artificial intelligence in healthcare: current status and future directions

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ABSTRACT

Generative artificial intelligence (GAI) is rapidly transforming the healthcare landscape, offering innovative solutions in areas such as medical imaging, drug discovery, and clinical decision support. This comprehensive review examines the current role of GAI in healthcare, its potential benefits, drawbacks, challenges, and future research directions. By synthesizing recent literature and expert perspectives, this review provides a critical analysis of GAI's impact on healthcare delivery, patient outcomes, and ethical considerations. While GAI shows promise in enhancing diagnostic accuracy, accelerating drug development, and improving healthcare efficiency, it also faces significant challenges related to data privacy, regulatory compliance, and ethical implementation. This review aims to inform healthcare professionals, researchers, and policymakers about the current state and future potential of GAI in healthcare, emphasizing the need for responsible development and deployment of these technologies.

Introduction

The advent of generative artificial intelligence (GAI) has ushered in a new era of innovation in many industries, including healthcare, promising to revolutionize various aspects of medical practice, research, and patient care.[1] GAI, which encompasses technologies such as generative adversarial networks (GANs) and variational autoencoders (VAEs), has demonstrated remarkable capabilities in generating realistic synthetic data, enhancing medical imaging, and assisting in drug design.[2] As these technologies continue to improve and evolve, it is crucial to critically examine their current role, potential benefits, drawbacks, and the challenges they present to the healthcare sector. It is paramount to assess their importance as accurately as possible.

This narrative review paper aims to provide a comprehensive overview of GAI in healthcare, synthesizing recent research and relevant expert perspectives to offer insights into its transformative potential and contemplate some of the ethical considerations that accompany its implementation. By exploring the current applications, benefits, challenges, and future trends of GAI in healthcare, the goal is to inform healthcare professionals, researchers, and policymakers about the opportunities and risks associated with these novel and emerging technologies.

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The current role of generative artificial intelligence in healthcare

GAI is currently being applied across various domains in healthcare, demonstrating its versatility and potential to improve patient health outcomes and healthcare delivery. Still, the current implementation levels are quite low.

Medical imaging and diagnostics

GAI models, particularly transformers and diffusion models, have significantly enhanced medical imaging capabilities. These technologies facilitate and enhance image reconstruction, image-to-image translation, image generation, and classification, leading to faster and improved clinical diagnosis and radiology interpretation.[3] This clearly means

that the application of GAI in medical imaging has the potential to increase diagnostic accuracy and efficiency, ultimately improving patient care.

Drug discovery and development

GAI models and algorithms are playing an increasingly important role in drug discovery and development processes. By leveraging advanced processes, GAI can assist in designing and synthesizing new, more efficient drugs, predicting molecular structures and properties, and accelerating the overall drug discovery timeline.[2] This application of GAI is still in its infancy but has the potential to significantly reduce the time and costs associated with bringing new treatments to market.

Synthetic data generation

One of the most promising applications of GAI in healthcare is the generation of synthetic patient data. Using models like GANs and VAEs, researchers can create realistic, anonymized datasets that preserve patient privacy while providing valuable resources for research and training purposes.[4] This approach helps address and establish the critical balance between data access and privacy protection in healthcare and medical research.

Clinical decision support

GAI systems are increasingly being integrated into clinical decision support systems (CDSS), offering healthcare professionals assistance in diagnostics, treatment planning, and patient management.[3] CDSS are very instrumental in modern healthcare settings, and any noticeable enhancements to these systems are paramount. Artificial intelligence (AI)-powered systems can analyze vast amounts of medical data to provide evidence-based recommendations, potentially improving the quality and consistency of care. This is especially true when relying on GAI models.

Further benefits of generative artificial intelligence in healthcare

Considering the status and taking advantage of the evolution of AI, especially GAI algorithms, we can expect that the integration of adequate GAI models into healthcare systems offers numerous potential benefits.

Enhanced diagnostic accuracy

Generative AI has shown significant potential for enhancing diagnostic accuracy across various medical fields. Indeed, GAI models can drastically improve the accuracy and speed of medical imaging analysis and interpretation, potentially leading to earlier and more precise diagnoses.[1] Moreover, generative methods can reduce diagnostic bias caused by training data imbalances. For instance, synthetic fundus images generated to address missing subpopulation data can improve diagnostic accuracy for diabetic retinopathy across different skin tones, achieving closer parity in accuracy between lighter-skin and darker-skin individuals.[5]

Moreover, generative AI models like GPT-4V show the potential for higher diagnostic accuracy using multimodal inputs (combining text and image sources) compared to text-only or image-only inputs. This approach aligns with confirmed diagnoses in a significant majority of cases, demonstrating the utility of integrating diverse data types for more accurate diagnostics.[6]

Another important facet related to enhanced diagnostic accuracy is the use of vision transformers combined with GANs. These can improve diagnostic accuracy by fusing medical images from different modalities (*e.g.*, X-rays and magnetic resonance imaging). This method preserves detailed information and improves the interpretability of diagnostic images, which is crucial for accurate medical assessments.[7]

Recent AI chatbots, like GPT-3 and beyond, can generate accurate differential diagnosis lists for common clinical complaints. Although human physicians still outperform AI in top diagnosis accuracy, the AI-generated lists show high diagnostic accuracy, suggesting that generative AI can support clinical decision-making.[8] This is an area where we see constant improvement and a clear potential for the future application of GAIs.

Domain-specific training for diagnostic reasoning is another important application of GAI models to improve diagnostic accuracy. Such models have the potential to be trained on domain-specific data and information and can, therefore, outperform other general models in clinical diagnostic tasks. Multi-task training with in-domain language models can significantly enhance performance in diagnostic reasoning, underscoring the importance of specialized training for clinical applications.[9]

GANs can also generate realistic samples that can be used to improve diagnostic accuracy under conditions with limited available training data. This approach is particularly effective and useful in fault diagnosis for rotating machinery, demonstrating high accuracy and stability even with small sample sizes.[10]

Moreover, GAI techniques, including GANs and VAEs, have the obvious potential to improve medical imaging by generating synthetic images, deeply enhancing image reconstruction, and facilitating disease diagnosis and treatment planning. These advancements and their potential large-scale implementation in healthcare settings highlight the transformative potential of GAI in medical imaging.[11]

From all the discussed literature, it is clear that GAI models can enhance diagnostic accuracy by addressing biases, integrating multimodal data, and leveraging advanced machine learning techniques. By generating synthetic data to mitigate biases, fusing diverse imaging modalities, and employing domain-specific training, generative AI models can significantly improve diagnostic outcomes. These advancements underscore the potential of generative AI to transform clinical diagnostics and support healthcare professionals in making more accurate and informed decisions.

Accelerated drug discovery

In the context of drug discovery, GAI has emerged as a transformative tool, leveraging deep learning models to design novel molecules with desired biological activities. This approach aims to accelerate the drug discovery process, reduce costs, and improve the success rate of identifying effective therapeutic compounds. Generative models can

significantly speed up and improve the drug discovery process, as demonstrated by the rapid design and synthesis of DDR1 kinase inhibitors in just 21 days.[12,13] The ability to quickly generate and test new compounds has also been highlighted as a major advantage, with several studies showing successful synthesis and biological evaluation of AI-designed molecules.[12,14] Additionally, generative models can be used to expand existing compound libraries by generating novel molecules that are similar and analogous to but distinct from those in the training set.[14,15] These models can also optimize the properties of generated molecules through techniques like reinforcement learning, enhancing their potential as drug candidates.[14,16] AI-driven generative models can design molecules with specific desired properties, such as high activity against particular and specific biological targets or favorable pharmacokinetic profiles.[14,15] Examples include the design of molecules with predefined anticancer properties using advanced generative adversarial autoencoder models.[17]

Furthermore, the application of GAI in drug discovery reduces the need for extensive human, material, and financial resources traditionally required in the drug design process.[14] This efficiency is achieved through the automated generation and evaluation of potential drug candidates, streamlining the overall workflow.[15] Besides, by predicting molecular structures and properties, GAI algorithms can significantly reduce the time and costs associated with drug development.[18]

GAI enhances drug discovery by accelerating the design and synthesis of novel compounds, expanding and optimizing compound libraries, and designing molecules with specific properties. While challenges in validation and benchmarking remain, the potential of generative models to transform drug discovery is evident, promising more efficient and cost-effective development of new therapeutics.

Further benefits and future directions

Beyond the aforementioned advancements in diagnostics and drug discovery, GAI offers additional advantages to the healthcare sector. Notably, GAI-driven synthetic data generation significantly enhances data privacy and security by providing medical and scientific researchers with valuable datasets while safeguarding patient confidentiality.[2] Moreover, GAI's ability to analyze vast datasets empowers the development of personalized medicine (precision medicine), enabling tailored treatment plans for specific patients based on individual characteristics and responses.[19] By automating routine tasks and providing intelligent decision support, GAI can assist with the streamlining of healthcare operations, potentially reducing costs and improving overall patient outcomes.[20]

To fully realize the potential of GAI in healthcare, several research avenues must be pursued. Prioritizing the enhancement of model accuracy, reliability, and robustness is essential to ensuring safe and effective clinical applications.[1] Moreover, it is crucial to start developing explainable AI models that transparently communicate decision-making processes to build trust among healthcare professionals.[20]

Exploring novel applications, such as remote patient monitoring and predictive analytics, will expand the impact of GAI on healthcare delivery.[19] These can be very useful in the context of smart homes, palliative care units, and in telehealth and telemedicine contexts in general.

Another important area of use can be based on a deeper exploration of the integration of GAI with other emerging technologies, such as blockchain and the Internet of Things.

Finally, fostering collaboration among AI researchers, IT professionals, healthcare practitioners, ethicists, and policymakers is vital for developing GAI solutions that effectively address the multifaceted and complex needs of the healthcare sector.[20]

Drawbacks and challenges

Despite its obvious and very interesting potential benefits, the implementation of GAI in healthcare faces several significant challenges. These challenges can slow down the implementation and uptake of such novel technologies and need to be assessed and addressed in a timely manner.

Data privacy and security concerns

The use of patient data to train GAI models raises important privacy and security concerns. Ensuring compliance with regulations such as the Health Insurance Portability and Accountability Act and the General Data Protection Regulation while leveraging the power of AI remains a significant challenge.[1] Such concerns are common for any technological solutions used in healthcare.

Ethical considerations and regulatory compliance

Addressing the ethical implications of GAI and establishing comprehensive regulatory and legal frameworks are imperative for responsible and beneficial implementation.[21]

Indeed, the deployment of GAI in healthcare raises numerous ethical questions, including issues of transparency, accountability, and potential biases in AI-generated outputs.[21] Ensuring that GAI systems are developed and used in an ethically responsible manner is crucial for maintaining public trust and preventing potential harm.

Moreover, the rapidly evolving nature of GAI technologies presents challenges for regulatory frameworks. Developing and implementing appropriate regulations, laws, and policies that ensure patient safety and data protection while fostering innovation remains a complex task.[1]

Integration with existing systems

Integrating GAI technologies with existing healthcare infrastructure and workflows can be technically challenging and resource-intensive. This is especially true for legacy systems and solutions. Ensuring seamless integration while maintaining the integrity, continuity, and efficiency of healthcare delivery is a significant hurdle.[1]

Quality and accuracy of artificial intelligence-generated outputs

While GAI models have demonstrated promise in various healthcare settings and applications, ensuring the quality, accuracy, and reliability of AI-generated outputs remains a critical challenge. The potential for "hallucinations" or in-

accurate outputs from GAI models poses risks in clinical settings and must be carefully managed.[22] Safeguards and review procedures should be established to ensure the quality and veracity of the generated data.

Conclusions

GAI holds immense promise for revolutionizing healthcare delivery, with applications spanning from diagnostics to drug discovery and personalized medicine. This review has elucidated the current state of GAI in healthcare, highlighting its potential benefits while acknowledging the significant challenges that must be addressed.

Realizing the full potential of GAI requires a concerted effort involving researchers, clinicians, policymakers, and industry stakeholders. Key priorities include enhancing model accuracy and explainability, establishing robust ethical and regulatory frameworks, and fostering collaborative research. By investing in these areas, we can mitigate risks and maximize the positive impact of GAI on patient care.

While challenges persist, the potential benefits of GAI are undeniable. As technology continues to advance, it is imperative to approach GAI development and implementation with a focus on patient safety, data privacy, and equitable access to care. By doing so, we can harness the power of GAI to improve health outcomes and build a more resilient healthcare system.

Ultimately, the successful integration of GAI into healthcare will depend on a balanced approach that considers both the opportunities and challenges presented by this rapidly evolving technology.

References

1. Kuzlu M, Xiao Z, Sarp S, et al. The rise of generative artificial intelligence in healthcare. 12th Mediterranean Conference on Embedded Computing (MECO). 2023;1-4.
2. Jadon A, Kumar S. Leveraging generative AI models for synthetic data generation in healthcare: balancing research and privacy. 2023 International Conference on Smart Applications, Communications and Networking 2023;arXiv:2305.05247.
3. Shokrollahi Y, Yarmohammadtoosky S, Nikahd MM, et al. A comprehensive review of generative AI in healthcare. 2023 Available from: https://arxiv.org/abs/2310.00795.
4. Arora A, Arora A. Generative adversarial networks and synthetic patient data: current challenges and future perspectives. Future Healthc J 2022;9:190-3.
5. Burlina P, Joshi N, Paul W, et al. Addressing artificial intelligence bias in retinal disease diagnostics. Transl Vis Sci Technol 2021;10:13.
6. Schubert M, Lasotta M, Sahm F, et al. Evaluating the multimodal capabilities of generative ai in complex clinical diagnostics. medRxiv Available from: https://www.medrxiv.org/content/10.1101/2023.11.01.23297938v1
7. Mansouri H, Barigou F, Nahili A, et al. Enhancing medical image fusion and diagnostic accuracy using vision transformers: a novel approach leveraging generative adversarial networks. All Sciences Abstracts 2023;1:8.
8. Hirosawa T, Harada Y, Yokose M, et al. Diagnostic accuracy of differential-diagnosis lists generated by generative pretrained transformer 3 chatbot for clinical vignettes with common chief complaints: a pilot study. Int J Environ Res Public Health 2023;20:3378.
9. Sharma B, Gao Y, Miller T, et al. Multi-task training with in-domain language models for diagnostic reasoning. Proceedings of the 5th Clinical Natural Language Processing Workshop. Toronto, Canada: Association for Computational Linguistics; 2023. pp 78-85.
10. Ding Y, Ma L, Ma J, et al. A generative adversarial network-based intelligent fault diagnosis method for rotating machinery under small sample size conditions. IEEE Access. 2019;7:149736-49.
11. Musalamadugu T, Kannan H. Generative AI for medical imaging analysis and applications. Future Med AI 2023;1:FMAI5.
12. Chen H, Engkvist O. Drug design augmented by artificial intelligence become a reality?. Trends Pharmacol Sci 2019;40:592-604.
13. Zhavoronkov A, Ivanenkov YA, Aliper A, et al. Deep learning enables rapid identification of potent DDR1 kinase inhibitors. Nat Biotechnol 2019;37:1038-40.
14. Tong X, Liu X, Tan X, et al. Models for de novo drug design. J Med Chem 2021;64:6305-21.
15. Lin E, Lin CH, Lane H. Relevant applications of generative adversarial networks in drug design and discovery: Molecular de novo design, dimensionality reduction, and de novo peptide and protein design. Molecules 2020;25:3250.
16. Zhavoronkov A, Aspuru-Guzik A. Reply to 'Assessing the impact of generative AI on medicinal chemistry'. Nat Biotechnol 2020;38:146.
17. Kadurin A, Nikolenko S, Khrabrov K, et al. druGAN: an advanced generative adversarial autoencoder model for de novo generation of new molecules with desired molecular properties in silico. Mol Pharm 2017;14:3098-104.
18. Walters W, Murcko M. Assessing the impact of generative AI on medicinal chemistry. Nat Biotechnol 2020;38:143-5.
19. Zhang P, Kamel Boulos MN. Generative AI in medicine and healthcare: promises, opportunities and challenges. Future Internet 2023;15:286.
20. Yu P, Xu H, Hu X, Deng C. Leveraging generative AI and large language models: a comprehensive roadmap for healthcare integration. Healthcare 2023;11:2776.
21. Oniani D, Hilsman J, Peng Y, et al. From military to healthcare: adopting and expanding ethical principles for generative artificial intelligence. Available from: https://arxiv.org/abs/2308.02448.
22. Shah C. Generative AI and the future of information access. Proceedings of the 32nd ACM International Conference on Information and Knowledge Management, 2023, October 21-25, Birmingham, United Kingdom. doi:10.1145/3583780.3615317.