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ChatGPT in medicine

A cross-disciplinary systematic review of ChatGPT's (artificial intelligence) role in research, clinical practice, education, and patient interaction

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Abstract

Background: ChatGPT, a powerful AI language model, has gained increasing prominence in medicine, offering potential applications in healthcare, clinical decision support, patient communication, and medical research. This systematic review aims to comprehensively assess the applications of ChatGPT in healthcare education, research, writing, patient communication, and practice while also delineating potential limitations and areas for improvement.

Method: Our comprehensive database search retrieved relevant papers from PubMed, Medline and Scopus. After the screening process, 83 studies met the inclusion criteria. This review includes original studies comprising case reports, analytical studies, and editorials with original findings.

Result: ChatGPT is useful for scientific research and academic writing, and assists with grammar, clarity, and coherence. This helps non-English speakers and improves accessibility by breaking down linguistic barriers. However, its limitations include probable inaccuracy and ethical issues, such as bias and plagiarism. ChatGPT streamlines workflows and offers diagnostic and educational potential in healthcare but exhibits biases and lacks emotional sensitivity. It is useful in inpatient communication, but requires up-to-date data and faces concerns about the accuracy of information and hallucinatory responses.

Conclusion: Given the potential for ChatGPT to transform healthcare education, research, and practice, it is essential to approach its adoption in these areas with caution due to its inherent limitations.

Abbreviations: AI = artificial intelligence, CAD = computer-aided detection, CT = computed tomography, GPT = Generative Pre-Trained Transformer, LLM = large language model, PRISMA = Preferred Reporting Items for Systematic Review and Meta-Analysis, USMLE = United States Medical License exam.

Keywords: academic writing, artificial intelligence, ChatGPT, digital health, ethical concerns, language models

1. Introduction

Artificial Intelligence (AI) is a branch of science and computational engineering that replicates and utilizes human intellect to perform various tasks.[1] Currently, we live in a technological era where everything is digitally recorded and with the increasing sets of recorded information and databases, the recognition and use of AI is inevitable. Machine learning, described as a sub-domain of AI, is the ability of auto-learning and improving from past observations and examples without the specific requirement of explicit programming. Computer systems use machine learning by interpreting various different algorithms and previous datasets to solve a problem or to particularly extract the purposeful relationships and patterns. With the ever-rising advancements in the field of computational technology and the very self-adaptive nature of AI, it has been constantly evolving with increasingly human-like capabilities.

A large language model (LLM) is a machine-learning model that can mimic human intelligence by analyzing vast amounts of data and predicting responses based on the preceding text. The Generative Pre-Trained Transformer (GPT), a well-known LLM and an adaptation of a basic transformer, was developed by OpenAI (San Francisco, CA) in 2018 and contains 110 million learning parameters.[2] The word "generative" implies that it can generate responses using the input data, while "pre-trained" refers to the vast quantities of data it has been trained

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on. Its largest publicly available version, GPT-3, with 175 billion parameters, is a third-generation autoregressive language model based on neural network deep machine learning that has made considerable advances in natural language processing, setting a new benchmark in AI language generation.[2,3]

Recently, ChatGPT-3.5, a modified version of GPT-3, was introduced by OpenAI in November 2022 as a chatbot model that is a highly refined and robust version of previously launched AI chatbots.[4,5] It has been trained on a large corpus of data, including books, websites, articles, journals, and various other online sources.[6] This pre-training has allowed it to achieve state-of-the-art results in natural language functions such as question-answering, coherent writing, problem-solving, and computational tasks.[7]

Furthermore, ChatGPT, compared to its previous counterparts, has been finely tuned for more challenging natural language processing tasks with improvements in response relevancy and accuracy, context understanding, and flexibility.[4,7] As a result, it can recognize nuances and complexities in human input, making it capable of generating human-like conversational texts or responses to various prompts and inquiries.[5,8] This makes it appropriate for engaging in dynamic discussions across a wide array of subjects. Moreover, an even more advanced and sophisticated version, ChatGPT-4, was launched in March 2023, with more creative and enhanced performance than its preceding version, ChatGPT-3.5.[9] Its ability to respond to inputs containing images, graphics, and other non-text data sources makes it unique and even more useful to humans.

Although AI LLMS have been extensively employed in various domains, such as marketing, data management, and customer support, their medical science and healthcare interventions have been relatively restricted. However, since its release, the AI ChatGPT has become a new medico-scientific sensation, attracting an audience with a wide array of exciting opportunities in healthcare and medicine. With its ever-increasing usage, ChatGPT is being exploited in many ways in almost every field of medicine and scientific academia. ChatGPT has been tested multiple times in professional examinations, and its responses reflect its ability to solve complex medical scenarios with logic and relevant informational contexts.[10,11] Regarding healthcare education and scientific writing, ChatGPT also exhibits bright, revolutionary potential to enhance and accelerate the processes of teaching, learning, and writing processes.[12,13] Furthermore, ChatGPT's implementation in clinical practice is an interesting area currently being explored, highlighting its potential benefits for improving the quality and efficiency of the healthcare system.

Although ChatGPT offers a range of promising implications in healthcare and medical science, it also raises several valid concerns about its usage. Scientific hallucination, for instance, is a well-known occurrence in ChatGPT that refers to false factual data appearing scientifically reasonable and accurate.[14] Additionally, the risk of bias and plagiarism, ethical, social, and medico-legal complications, data accountability, quality, transparency, the risk of overreliance, and technological drawbacks are other possible shortcomings that must be addressed to enhance its use broadly.[15]

This review aims to provide a comprehensive overview of the current capabilities and limitations of ChatGPT in medical science, healthcare research and education, scientific writing, and clinical settings based on the current evidence. Additionally, the review will provide insights into future possibilities and recommendations to prevent improper use.

2. Methodology

2.1. Search strategy

Per the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) guidelines, the electronic databases PubMed, Medline, Embase and Scopus were systematically searched for all publications related to ChatGPT since its inception up to the 17th of May 2023. The search strategy "ChatGPT" was used to obtain all studies on ChatGPT. The identified records were screened based on titles, abstracts, and full texts by all authors, and any disagreements were resolved by discussion among the authors. No sources other than those used in the PRISMA guidelines were used.

2.2. Eligibility criteria

The themes of academic writing, clinical practice, education. and patient interaction did not play a role in the decision regarding the eligibility of a study. The eligibility was only decided based on the inclusion and exclusion criteria outlined in the section on eligibility criteria. Once the studies were selected, they were put into categories.

All English academic articles that had one of the following study designs were selected for this systematic review: research article with a predefined methodology and statistical analysis; case Reports written with the assistance of ChatGPT with the authors sharing their experience with ChatGPT; and editorials with excerpts from authors' conversations with ChatGPT and original findings resulting from those conversations.

The following types of publications were excluded from this review: those in languages other than English, preprints, opinion pieces, narrative reviews and editorials without original findings or observations, and research articles written using ChatGPT without evaluating its strengths and weaknesses.

2.3. Study identification and selection

Our search of the databases yielded a total of 1333 studies. After removing duplicates and unavailable studies, 434 studies were screened for inclusion. During the vetting process, 45 preprints, 302 editorial pieces, and 4 studies that were not in English were excluded. Hence, 83 studies were included in this systematic review, referenced as,[16–50] and.[10,11,51–96] The detailed selection criteria are depicted in PRISMA flow chart (Fig. 1).

Each study was carefully read and analyzed and it was found that on the whole, each study focused on only one theme. For example, an analytical study with a research question regarding ChatGPT's ability to answer United States Medical License exam (USMLE)-style questions falls into the category of medical education. A research paper written with the help of ChatGPT, with comments by the author falls into the category of academic writing. A research paper with the aim to assess the answers provided by a patient's questions regarding a topic, fall into the category of patient communication. Hence, the categories were very distinct and it was easy to categorize the research papers.

All discussions present in the studies were carefully read and each strength and weakness of ChatGPT mentioned in the study was compiled in a spreadsheet. Papers that only mentioned the strengths of ChatGPT were said to give a positive verdict. Meanwhile, studies with only weaknesses were said to give a negative verdict. Whereas, studies that mentioned both were said to have a neutral verdict. This delineation of strengths and weaknesses can be seen in our Tables 1–4.

3. Results

3.1. Study categorization

The included studies were found to analyze the role of ChatGPT in academic writing, Clinical practice, medical education, and patient communication. Most studies discussed more than one theme to varying degrees, but each study was sorted into one of the 4 categories based on its overarching theme. Figure 2 exhibits the number and types of studies in each category.

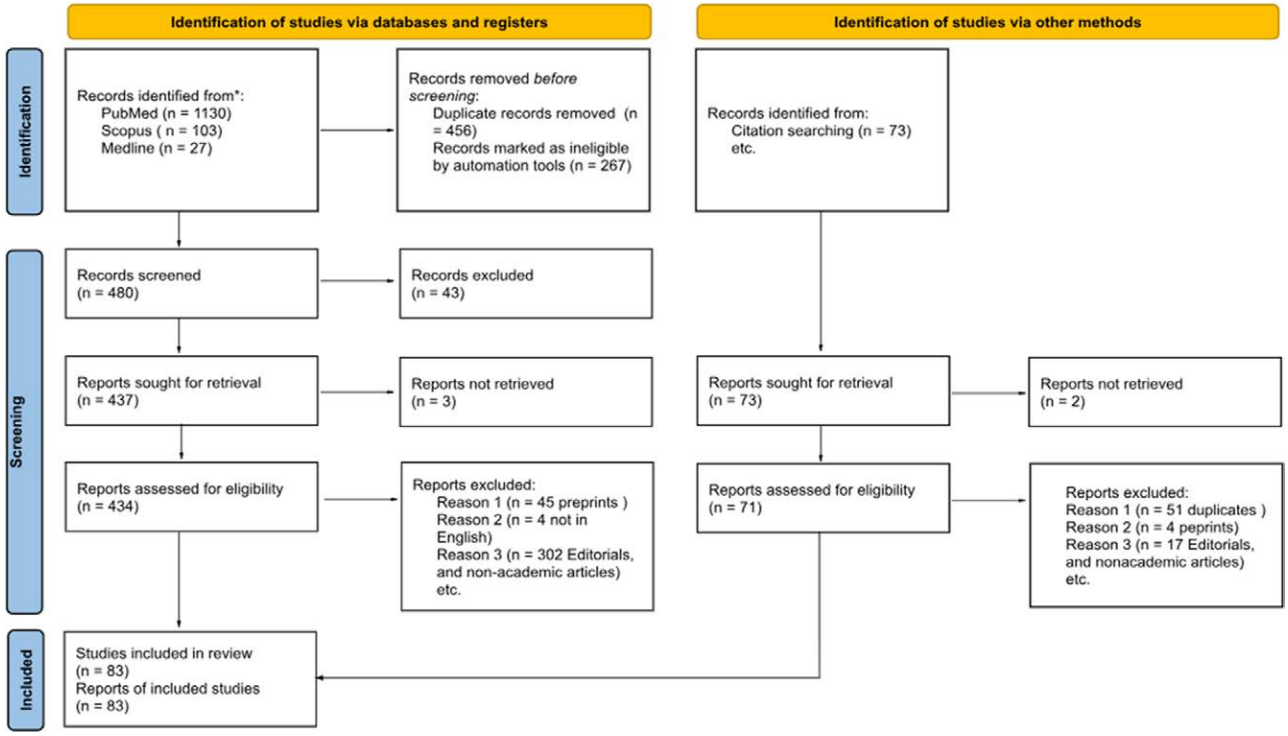

Figure 1. Prisma flow chart.

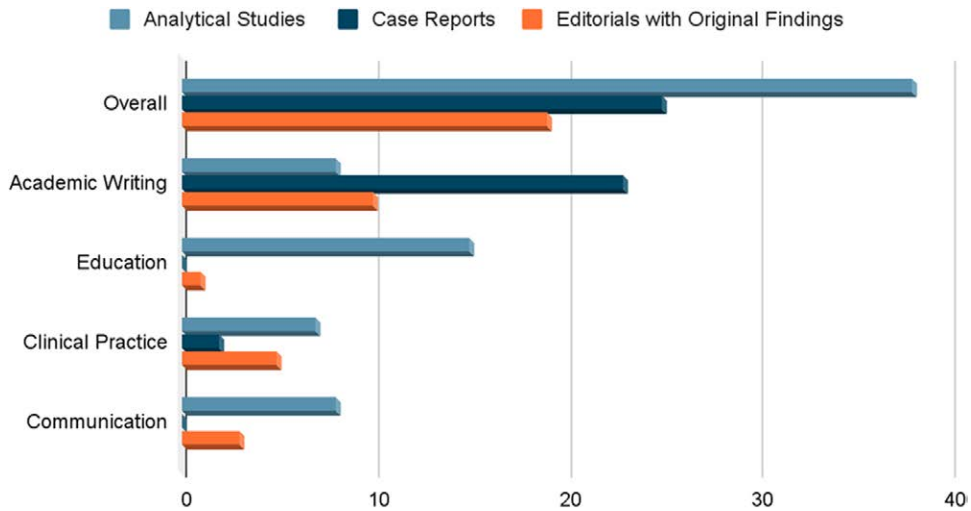

Figure 2. Of the 83 studies included in this review, there were 39 analytical studies, 25 case reports, and 19 editorials with original findings. Most of the papers focused on the usage of ChatGPT in academic writing and research, followed by papers on education, clinical practice, and education in that order.

ChatGPT's role in scientific research and academic writing was discussed the most and had 41 studies written on it. The second common theme was ChatGPT's potential in medical education and the performance in examination questions from various specialties, and a total of 16 papers were written on this theme. ChatGPT's utility in clinical practice and its benefit to physicians was assessed in 15 studies. ChatGPT's potential to help healthcare institutions communicate with patients through discharge summaries and letters and its capacity to provide accurate answers to the general public's health-related questions was the least explored area, with only 11 studies published on it.

All 4 categories contain published articles with diverse study designs. Overall, Analytical studies with a clearly defined methodology were the most common studies encountered during this systematic review. This lends a strong confidence to our understanding of ChatGPT and the findings of this review. The study designs of included studies in each category have been illustrated in Figure 2.

3.2. Summary of studies

All included studies were analyzed, and their major findings regarding the usage of ChatGPT were identified. The subsequent tables have been created based on the identified discoveries. The strengths and weaknesses of ChatGPT in the domain of academic writing explored in the included literature have been summarized in Table 1.

Table 1

The role of ChatGPT in academic writing.

Author, Year	Strengths	Weaknesses	Study type
Cunningham et al, 2023[1]	It is apt for creating concise summaries and writing entire paper sections from basic points.	ChatGPT has a knowledge cutoff of 2021, no access to the internet, repetitive paragraphs, and suboptimal grammar. Use medical terms that do not exist.	Case report
Macdonald et al, 2023[2]	ChatGPT could greatly help researchers worldwide design their studies, conduct analyses, and draft their research articles.	Its frequent use may result in excessively similar paragraphs and structures in numerous papers in the same field, causing problems with plagiarism checks.It needs human oversight in all stages and final input to guarantee the accuracy of the reported results. References provided by ChatGPT cannot be trusted at present.	Editorial with original findings
Alkaissi & McFarlane, 2023 [3]	ChatGPT can make a linguistically coherent text out of scattered bullet points provided by the research author. When asked to write a Python code to identify such PMID numbers (5 integers or more), the code successfully identified all recurrent PMID numbers within the text.	ChatGPT can hallucinate	Editorial with original findings
Gupta et al, 2023[4]	When asked to provide novel ideas for a systematic review, ChatGPT was 35% accurate for general ideas and 75% accurate for specific ideas.		Analytical study
Manohar & Prasad, 2023[5]	Generated clear, understandable text that could pass for printed literature. Additionally, it generated references in the right format.	Chatgpt provided inaccurate citations	Case report
Le & Hall, 2023[6]	Generated a foundational organization and the design for the case report with a cohesive and logical response. The references were also provided in the correct format.	Chatgpt cannot understand the nuances and intricacies of clinical cases or research studies. Inaccuracies were found within the automated references	Case report
Akhter & Cooper, 2023[7]	Chatgpt aided in composing the case report by providing a relevant general introductory summary, proofreading, and adjusting the wording. A valuable tool to help augment and quicken the act of manuscript writing	Chatgpt provides inaccurate references, can not access information after 2021, and cannot critically discuss results and literature.	Case report
Raxwal et al, 2023[8]	Chatgpt is a useful tool in academic writing.	Chatgpt lacks originality, creativity, and critical thinking; hence, it cannot produce completely original arguments and critically evaluate research information. It has a limited understanding of citation and referencing and may be unable to cite them properly. It lacks context and may be unable to make appropriate connections between different pieces of information.	Case report
Jansz et al, 2023[9]	Chatgpt can summarize a topic well.	It makes inaccurate factual statements and is only knowledgeable about topics up to 2021, limiting its ability to comment on recent literature.	Case report
Hallo-Carrasco et al 2023[10]	Chatgpt was used to remove redundancies and streamline the case report.	It currently cannot provide valid citations or high-quality sources. Chatgpt focuses on structured and straightforward writing without considering the hypotheses, suspicions, and nuances that are fundamental in academic writing.	Case report
ilan-Ortiz et al, 2023[11]	Chatgpt allowed the author to write a comprehensive literature review of the latest information by consolidating the author's thoughts.	ChatGPT is limited in providing sources for its statements and cannot provide references for its writing,	Case report
Dergaa et al, 2023[12]	Chatgpt can process vast amounts of textual data in a short period, which can save researchers significant time and effort. It can be utilized to analyze academic papers by scanning them and extracting important details. Aid in creating summaries and generating research questions.	ChatGPT generated a response containing factual errors and misrepresentations that could be attributed to its incapacity to differentiate between credible and less credible sources. The lack of transparency in the training sets and LLMs underlying ChatGPT can cause biases and unintentional plagiarism.	Review with verbatim responses of Chatgpt
Schussler et al, 2023[13]	Chatgpt helped to generate initial drafts of the various sections of the article. Its ability to generate text based on input prompts has allowed for the rapid creation of high-quality content		. Case report
Moreira et al, 2023[14]	Chatgpt assisted in the article's development as a research tool and generated arguments used in the article's introduction and discussion and in translating the article into the English language		Case report
Naik et al, 2023[15]	ChatGPT assisted in the composition of the final version of the manuscript. It was useful in generating a skeletonized outline and logically organizing thoughts about the subject.	The numbers and the citations produced by Chatgpt were entirely fictitious.	Case report
Lantz, 2023[16]	ChatGPT assisted the author by providing background information about the disease, drug interactions, and references that can be added to support the study.	Chatgpt provided 7 references, of which 4 were non-existent. Most of the references were 10 years or older.	Case report
Tomar et al, 2023[17]	Chatgpt aided the authors by identifying the implications of drain usage in total knee arthroplasty. The authors incorporated its suggestions in the final manuscript with relevant references.		Case report

(*Continued*)

Table 1

(*Continued*)

Author, Year	Strengths	Weaknesses	Study type
Schuppe et al, 2023[18]	ChatGPT can be instrumental in identifying discussion points and clarifying language for the readers of medical literature. ChatGPT was used to edit and explain the written components of this case report.	Chatgpt was unable to provide accurate and relevant references.	Case report
Lynch and Tomboc, 2023[19]	Chatgpt provided a reasonable comparison of different conditions.	Chatgpt only has access to information until 2021 and asks for transparency about the source of the information. It tends to reiterate information in slightly varied ways, making it appear relatively superficial.	Case report
Charrois-Durand C et al, 2023[20]	Chatgpt extracted information pertinent to the case report when provided with a list of human-picked references.	It started to write a fictional case report despite being provided with accurate clinical information earlier.	Case report
Bawa et al, 2023[21]	Chatgpt aided the authors in writing the introduction and discussion sections of the case report.	It provided fake references. The text generated by ChatGPT needs to be thoroughly verified to ensure the information is correct.	Case report
Ching et al, 2023[22]	Chatgpt can assist authors in writing medical case reports, including outlining, referencing, summarizing studies, and formatting citations. It can also assist in generating concise descriptions of medical histories, physical examinations, and laboratory findings.	ChatGPT has a knowledge cutoff date of 2021.	Case report
Lahat et al, 2023[23]	chatGPT generated relevant and clear research questions and demonstrated excellent results in clarity, relevance, and satisfactory performance in terms of Specificity.	Chatgpt performed inadequately in terms of originality.	Analytical study
Zamarud et al, 2023[24]	This case report's introduction, results, and discussion were drafted using ChatGPT and showed high accuracy and consistency in its outputs.	ChatGPT does not have direct access to specific databases such as PubMed	Case-report
Najafali et al, 2023[25]	ChatGPT is impressive in its ability to automatically generate an editorial for a complex, challenging topic with actionable items.	Current limitations of ChatGPT include inappropriate references, inaccurate information, gender bias, and inability to answer discrete questions	Editorial written by ChatGPT
Kim HY, 2023[26]	. ChatGPT can be used in a case report to help record and report the patient's medical history, diagnosis, and treatment.	ChatGPT did not provide specific diagnostic or treatment recommendations for the patient's condition. It only assisted the doctor in determining what was wrong and how to treat it. The ethical implications of using AI tools such as ChatGPT to make medical decisions must be considered.	Case report
Segal & Khanna, 2023[27]	Chatgpt helped the authors present a case and write an introduction and conclusion.	The citations produced were entirely fictitious. ChatGPT has no semantic understanding of the text it writes, leading it to generate fluent but erroneous prose.	Case-report
Ariyaratne et al, 2023[28]		Most articles generated by ChatGPT were factually inaccurate, and all contained fictitious references.	Analytical study
Branum & Schiavenato, 2023[29]		ChatGPT generated PICOT formats that appeared credible but contained inaccurate or fabricated data. The lack of data transparency introduces bias in the generated content.	Analytical study
Gupta et al, 2023[30]	ChatGPT had a 65% accuracy in suggesting topics for systematic reviews in plastic surgery.	Since ChatGPT has a knowledge cutoff of 2021, it may not be able to provide the latest information.	Editorial with original findings
Qureshi et al, 2023[31]	ChatGPT's strengths in systematic reviews include contextual understanding, generating search strategies, basic coding assistance, and initial information summarization.	ChatGPT's weaknesses are its lack of expertise, verification, and suitability for complex tasks.	Editorial with original findings
Cheng et al, 2023[32]		ChatGPT doesn't always provide a concise answer with critical analysis; instead, it provides a generic answer to avoid getting wrong. Moreover, ChatGPT could falsify data. There is much inaccurate information online about Mpox. It could use that information to produce inaccurate results	Editorial with original findings
Marchandot et al, 2023[33]	Using ChatGPT, a researcher can analyze thousands of research papers quickly, saving time, assisting with literature reviews, identifying relevant papers, and summarizing key findings.	Using ChatGPT in academic research poses risks of inaccurate and biased results, decreased critical thinking, and ethical concerns such as potential plagiarism.	Editorial with original findings
Cheng et al, 2023[34]	ChatGPT can be very helpful in 1. Information dissemination 2. Disease surveillance and monitoring 3. Diagnosis and treatment 4. Risk assessment and modeling 5. Vaccine development: ChatGPT could help researchers identify potential vaccine targets by analyzing genomic data and predicting the antigenicity of different viral proteins.	1. Misinformation 2. Lack of human interaction 3. Legal and ethical concerns 4. Accessibility: ChatGPT requires Internet access and may not be accessible to all patients or healthcare providers, particularly in areas with limited connectivity	Editorial with original findings

(*Continued*)

Table 1

(Continued)

Author, Year	Strengths	Weaknesses	Study type
Vaishya et al, 2023[35]		ChatGPT lacks current medical literature knowledge, gives inaccurate data, and inconsistent responses. Limited image presentation hinders comprehensive medical understanding.	Analytical study
Babl & Babl, 2023[36]	ChatGPT generated a well-written article with proper headings and word length. The title, intro, results, and conclusions are accurate and align with current knowledge. No apparent errors were noted.	One of the references was made up	Analytical study
Praveen & Vajrobol, 2023[37]	The sentiment analysis results show that the majority of the sentiment of healthcare researchers regarding ChatGPT is either positive or neutral.	ChatGPT provided fictitious references.	Analytical study
Athaluri et al, 2023[38]		The phenomenon of AI hallucination raises concerns about its impact on decision-making, potentially leading to ethical and legal ramifications. Out of the 178 references analyzed, 69 did not have a Digital Object Identifier (DOI), and 28 did not turn up on Google search nor had an existing DOI.	Analytical study
Nachshon et al, 2023[39]	ChatGPT can write a whole case report if we provide the essential information.	It can provide background information but cannot produce a proper scientific report, even when describing a simple case. The bot provides facts but can not comment on the emotional and moral aspects of the case. There are ethical concerns associated with ChatGPT authoring complete papers.	Case report
Hegde et al, 2023[40]	ChatGPT excels in accurately answering and resolving simple and common questions and can be used with supervision to stitch together a well-written manuscript.	ChatGPT tends to offer relevant yet somewhat vague responses when faced with complex tasks. Hence, authors should be cautious as it can easily mislead them with well-written text and distorted facts	Case report
Wittmann J, 2023[41]		ChatGPT is inadequate for accurate scientific writing due to limited knowledge, errors, and inability to grasp complexity. Extensive human review and source replacement are needed for reliability.	Editorial with original findings

The use of ChatGPT in medical education and its proficiency in answering exam-style questions have been compiled in Table 2. The advantages and disadvantages of utilizing ChatGPT in clinical practice have been organized in Table 3.

Table 4 comprehensively outlines both the strengths and weaknesses of ChatGPT in its ability to provide accurate and easily understandable responses to health-related questions from the general population. Additionally, it highlights ChatGPT's proficiency in generating discharge summaries and patient notes.

3.3. Holistic review of ChatGPT

Using significant findings identified from the included literature, each study underwent an examination to determine whether it provided a neutral, positive, or negative assessment of ChatGPT usage.

It was observed that most articles (n = 58) gave a neutral verdict regarding the usage of ChatGPT across all categories. A negative verdict was the second most common judgment seen with n = 13. The majority of negative outcomes (n = 6) were seen in the articles pertaining to the usage of ChatGPT in the realm of research and academic.

A completely positive outlook on ChatGPT was the least common and was found in only 12 studies. Major trends observed in the literature published about ChatGPT are depicted in Figure 3.

In this systematic review, we analyzed the strengths, weaknesses, opportunities, and threats (SWOT) associated with ChatGPT in various applications (Fig. 4). The SWOT analysis provides a comprehensive framework for understanding the potential benefits and challenges of integrating ChatGPT into medical science and healthcare.

4. Discussion

Among the several LLMs, ChatGPT distinguishes itself as a groundbreaking tool in scientific research, impacting both the academic writing process and the research journey. Numerous sources have highlighted its efficacy and potential in conducting extensive literature reviews and automating code production, freeing up significant research time, especially when complex activities such as experimental design necessitate increased human involvement.

Hence, the primary objective of this review is to draw attention to these reports, drawing from the most up-to-date evidence. An examination of existing literature has uncovered prominent themes.

4.1. Benefits of chat GPT in writing

ChatGPT presents a diverse range of supplementary advantages beyond its fundamental functionalities. In addition to its primary role as a tool for improving grammar, fluency, and overall cohesiveness of written text, ChatGPT serves as a critical factor in enhancing the overall excellence of content. It assists researchers and writers in refining their manuscripts, ensuring they adhere to the most stringent standards of clarity and coherence, as documented in various sources.[17,18,97–100] Moreover, it is worth highlighting that the impact of ChatGPT extends beyond the confines of the linguistic elements. This significantly contributes to the comprehensibility and impact of research outputs, transcending language barriers.[16] This comprehensive enhancement makes research findings more accessible to a broader audience, potentially amplifying their significance and relevance within the academic community, as evidenced by numerous studies.[19,20,22,23,101–103] Several studies have reported the effectiveness of ChatGPT in academic English writing, particularly in assisting non-English speakers. It has proven to be instrumental in elevating the quality of their work and helping them achieve higher levels of excellence.

4.2. Limitation of writing

When implementing ChatGPT in academic writing and scientific research, it is important to be aware of the following constraints that could compromise the research quality. First, shallow, erroneous, or wrong information is commonly highlighted as a drawback of ChatGPT in scientific writing.[27,38,48,99,101] In addition to the lack of transparency regarding content generation, which justifies the description of ChatGPT as a black-box technology, on occasion, ethical issues, such as the risk of bias based on training datasets and plagiarism, were frequently mentioned. Importantly, if academics and health clinicians do

Table 2

The role of ChatGPT in education and examinations.

Author, Year	Strengths	Weaknesses	Study type
Huh, 2023[1]		ChatGPT's performance lagged behind medical students. It struggled with visuals, lacked Korea-specific data, and misunderstood multiple-choice questions due to limited knowledge, hindering its suitability for medical testing.	Analytical study
Gilson et al, 2023[2]	ChatGPT's dialogic interface helps students understand medical concepts, diagnoses, and treatments. ChatGPT answered over 60% of questions on USMLE Step 1 and Step 2 topics accurately – meeting passing standards and performing like a third-year medical student.		Analytical study
Kung et al, 2023[3]	ChatGPT's consistent, insightful medical explanations approach the USMLE pass range, outperforming a biomedical counterpart, with varying accuracy across exam levels.	ChatGPT provided some wrong answers driven primarily by missing information, leading to diminished insight and indecision in the AI rather than over-commitment to the incorrect answer choice.	Analytical study
Sevgi et al, 2023[4]	Chatgpt can help instructors save time by paraphrasing and correcting texts and by automatically generating exam questions.	Chatgpt scored 30% less than an average medical student on a standardized test. Sometimes, it gives wrong answers to even simple questions. The lack of citations for the text produced by the chatgpt casts doubt on the credibility of the information and raises plagiarism concerns.	Analytical study
Ghosh & Bir, 2023[5]	Chatgpt can be used to answer higher-order reasoning questions in medical biochemistry. It is an excellent tool for solving multiple choice. questions.	ChatGPT exhibited superior performance with traditional concepts compared to recent advancements, primarily due to limitations in its training data.	Analytical study
Li et al, 2023[6]	ChatGPT quickly produced accurate, relevant, structured answers for complex clinical questions in unfamiliar scenarios, surpassing humans in various knowledge areas. Not all examiners were able to discern between human and ChatGPT responses.		Analytical study
Oh et al, 2023[7]	Chatgpt displayed an accuracy of 76.4% with GPT-4 and 46.8% with GPT-3.5 on questions from the Korean General Surgery Board exam. Remarkably, this accuracy was achieved without fine-tuning the model and by using prompts in the Korean language exclusively,		Analytical study
Ali, 2023[8]		Answers produced by ChatGPT contained inaccuracies of varying degrees and contained no citations. Due to a lack of transparency, ChatGPT has the potential to exhibit bias in its responses.	Analytical study
Wagner & Ertl-Wagner, 2023[9]	Eighty-eight questions were submitted to ChatGPT-3 using a textual prompt; 59 of 88 responses (67%) to radiological questions were correct, while 29 responses (33%) had errors.	Bogus references were provided in 38% of the cases.	Analytical study
Fijačko et al, 2023[10]		ChatGPT could not pass a life support exam because, as an AI model, it largely relies on data but lacks logical reasoning. This study shows that we can't solely use ChatGPT in life-saving fields	Analytical study
Alberts et al, 2023[11]		50 radiology questions were administered to ChatGPT, and it was correct only 34% of the time (17/50). Examiners found the evidence of confabulation as instead of stating that it doesn't know the answer, ChatGPT ventured to provide a superficial and possibly convincing answer, which was wrong,	Editorial with original findings
Bhayana et al, 2023[12]	ChatGPT passed the radiological exam and scored 69%.	It performed better on questions requiring lower-order thinking than on those requiring higher-order thinking, hence highlighting the failure of Chatgpt in solving complex questions. Chatgpt can not interpret radiological images; hence, all prompts must be in the text.	Analytical study
Humar et al, 2023[13]	ChatGPT performs at the level of a first-year resident on the Plastic Surgery In-Service examination.	However, it performed poorly compared to residents in more advanced years of training.	Analytical study
Sinha et al, 2023[14]	ChatGPT scored approximately 80% on pathology questions; hence, academicians or students can also get help from the program for solving reasoning-type questions.	Chatgpt fails to answer high-level order reasoning scenarios	Analytical study
Mihalache et al, 2023[15]		ChatGPT lacks recent data and answers only according to old existing data. This shows its very important to update the AI data regularly. ChatGPT answered only 46% of the questions correctly.	Analytical study
Hopkins et al, 2023[16]	ChatGPT answered 60.2% of the questions without images correctly.	ChatGPT's weaknesses include struggling with image-based questions, yielding a 3.9% refusal rate, and inconsistent performance across neurosurgical categories.	Analytical study

Table 3

Role of ChatGPT in clinical practice.

Author, Year	Strengths	Weaknesses	Study type
Vallath et al, 2023[1]	It can play a crucial role in improving patient care by providing quick and relevant information and support		Case report
Saliba & Boitsios, 2023[2]	Another use case of ChatGPT for the radiologist is looking up normal criteria or classic signs in certain pathologies. In our experience, it provides fairly reliable information about common pathologies.	ChatGPT Provide an inaccurate answer. The references were found to be non-existent.	Editorial with original findings
Jungwirth & Haluza, 2023[3]	ChatGPT is a cost-efficient tool to assemble and summarize relevant text for public health concerns. It can assist people in accessing remote or automated health services, tracking and monitoring health data, symptoms, and treatments automatically, or providing emotional support for mental health difficulties. Chatgpt helps patients manage chronic conditions such as diabetes, hypertension, and asthma.	ChatGPT may not be able to handle complex conversations and nuanced topics. ChatGPT fabricated references.	Analytical study
Hirosawa et al, 2023[4]	ChatGPT-3 can generate well-differentiated diagnosis lists for common chief complaints.	The lack of transparency and the presence of gender, racial and religious biases in chatgpt can lead to poor ethical decisions and can harm the patients. Hence, efficient and accurate auditing algorithms and systems are needed to fact-check chatgpt.	Analytical study
Hassan et al, 2023[5]	In surgery, ChatGPT can evaluate real-time patient data like vital signs and images, aiding surgeons with advice for optimal decisions, potentially minimizing complications and enhancing efficiency.	AI will always carry the risk of bias and errors. In the event of an error, the question of responsibility for such malpractice will always arise.	Editorial with original findings
Moons & Van Bulck, 2023[6]	It can be accurately used for patient education, charting and documentation, Medication management, Research assistance, and Language assistance.	In the academic world, concerns regarding the ethical issues have been raised. There are even cases in which ChatGPT was included as a coauthor	Editorial with original findings
Liu et al, 2023[7]	AI-generated suggestions are valuable for enhancing CDS alerts, identifying alert logic enhancements, facilitating implementation, and aiding experts in formulating their own CDS improvement ideas.	A lack of knowledge management hindered AI suggestion acceptance.The suggestions included fabricated data that Chatgpt had hallucinated. Expert Review is necessary before the implementation of suggestions provided by ChatGPT.	Analytical study
Thirunavukarasu et al, 2023[8]		overall performance of ChatGPT was 60.17%, which is below the mean passing mark in the last 2 years (70.42%). Moreover, the explanations provided by ChatGPT were of poor quality, lacked conciseness, and carried a high risk of bias. While it can offer assistance, relying solely on ChatGPT is unsuitable for medical practice.	Analytical study
Alhasan et al, 2023[9]	ChatGPT could be utilized to generate medical advice and guidelines, with its ability to analyze vast amounts of databases,	There is a potential for biased or incomplete information based on the data it was trained on and the risk of providing inaccurate information that may not take into account individual patient factors or medical history	Case report
Almazyad et al, 2023[10]	ChatGPT can improve healthcare learning by autonomously creating cases, promoting critical thinking, and aiding DNR conflict resolution through key theme summarization: communication, collaboration, patient-centered care, trust, and ethics.	Biased information and validation of answers provided by chatGPT are of major concern.	Analytical study
Boßelmann et al, 2023[11]	It is very helpful and accurate while describing well-established facts and proven medical answers, like adverse effects of drugs a patient might be facing, Not only that, it can also provide accurate reasoning for this	It failed to describe and conclude disputed and complex questions and scenarios, as in many cases reported it generated biased answers and information which does not exist	Editorial with original findings
Cadamuro et al, 2023[12]	ChatGPT recognized all laboratory tests, and it could detect if they deviated from the RI and gave a test-by-test and an overall interpretation.	It can interpret results superficially only, and it can only assist in making a diagnosis, but it is not helpful when chatGPT starts making reports from that Lab results	Analytical study
Lu et al, 2023[13]	ChatGPT can play a role in several aspects of the management of ECMO, ventilators, defibrillators and ECG.		Editorial with original findings
Balel, 2023[14]	ChatGPT holds promise for patient information in oral and maxillofacial surgery,	The safety of using ChatGPT for training is uncertain. Surgeons should use ChatGPT cautiously, alongside clinical expertise.	Analytical study

not adequately assess the information created with appropriate knowledge, the idea of ChatGPT hallucinations may be dangerous.[21,23,24] This is because of the capacity of ChatGPT to create inaccurate information that seems logical from a scientific standpoint. Arguably, the most crucial concern surrounding ChatGPT is the potential for "hallucination." This term refers to generating content that appears scientifically plausible but may contain fundamental inaccuracies.[18,38,104] To address this issue, experts in their respective fields must conduct thorough evaluations to mitigate this risk, emphasizing the importance of their involvement in the process.

4.2.1. ChatGPT, a virtual author?. In our investigation, we came across several instances where ChatGPT was attributed as an author, which underscored the initial confusion experienced by certain publishers regarding the role of Language Models such as ChatGPT in research.[105,106] Nevertheless, it is crucial to emphasize that prominent editorial pieces explicitly rejected the practice of including ChatGPT or any other language model as authors, categorizing it as scientific misconduct. This standpoint garnered extensive support within the scientific community.[100,102,107–109] Regarding the application of ChatGPT in research, multiple sources emphasized the significance of transparent and concise disclosure and documentation of

Table 4

The role of ChatGPT in patient communication.

Author, Year	Strengths	Weaknesses	Study type
Ali et al, 2023[1]	it is possible to generate clinic letters with a high overall correctness and humanness score with ChatGPT. Furthermore, these letters were written at a reading level that is broadly similar to current real-world human-generated letters.	Mitigating potential risks in healthcare AI is crucial due to errors' serious patient care consequences. Accurate reporting and interpretation through regulated and monitored AI use are vital.	Analytical study
Lee et al, 2023[2]	This study suggests a potential role of conversational AI programs in optimizing the communication between patients and health care providers, especially for high-volume procedures like colonoscopy. Despite similar ratings, there was little overlap or plagiarism between the AI and non-AI answers	–	Analytical study
Cohen, 2023[3]	Chatgpt can be used to create and augment educational materials for patients and help them design a headache diary.	ChatGPT not only could be wrong, but the AI model could generate and confabulate incorrect information. ChatGPT does not provide references or citations with its responses; therefore, it is uncertain what information is used to generate its responses	Editorial with original findings
Cox et al, 2023[4]	Chatgpt provided quick and safe medical advice that had sufficient depth and and no excessive medical jargon.	Chatgpt can not provide personalized advice and due to its knowledge cutoff of 2021, its advice does not reflect the current and updated guidelines.	Analytical study
Johnson et al, 2023[5]	ChatGPT delivers factual information without providing users with misleading or dangerous information. The answers remain accurate even with repetitive questioning.		Analytical study
Sallam et al, 2023[6]	ChatGPT might be used as a user-friendly source of COVID-19 vaccination information, challenging conspiracy theories with clear, simple, and unbiased content.	ChatGPT content cannot be used as an alternative to the original reliable sources of vaccine information (e.g., the World Health Organization [WHO] and the Centers for Disease Control and Prevention [CDC]).	Analytical study
Juhi et al, 2023[7]	40 different types of drugs were tested for DDI, and ChatGPT responded accurately with only one wrong answer, Patients, who may not have immediate access to the healthcare facility for getting information about DDIs, may take help from ChatGPT		Analytical study
Xie et al, 2023[8]	The findings indicate that ChatGPT holds promise as a valuable source of information for patients in medical settings, particularly when patients might be hesitant to consult medical professionals or face limited access to medical advice.	Further research and development are necessary to ensure its accuracy, safety, and ethical implementation to maximize its potential benefits in healthcare.	Editorial with original findings
Hopkins et al, 2023[9]	ChatGPT demonstrated an ability to formulate interpretable responses which were similar in quality and content to Google's featured snippet.	ChatGPT does not have access to the internet, does not provide references, can provide inaccurate answers, and causes alarm to the patients by exaggerating the symptoms.	Editorial with original findings
Ayers et al, 2023[10]	Of the 195 questions and responses, evaluators preferred chatbot responses to physician responses in 78.6% of evaluations.		Analytical study
Tekinay, 2023[11]		It gave a lot of inaccurate and biased answers due to internal bugs and human error. Furthermore, there are serious concerns regarding the privacy and security of patients and user data	Analytical study
Singh et al, 2023[12]	ChatGPT has the potential to deliver customized responses based on input quality, swiftly write operative notes and discharge summaries, and adapt and learn from mistakes.	The ophthalmic discharge summaries were generic and the notes contained errors.	Analytical study

ChatGPT or Language Model involvement, particularly within the methodology or Acknowledgments sections.[15,108,110,111]

4.2.2. Falsifying and inaccurate references. Furthermore, several studies have pointed out that ChatGPT often fails to provide accurate citations. When prompted to do so, it generates references that do not exist. Moreover, a significant issue arises when its references do not align with the content they are meant to support. These instances further emphasize the need for caution and thorough verification when using ChatGPT-generated content in research materials (46-49). In summary, concerns about citation inaccuracies, insufficient references, and ChatGPT referencing non-existent sources, along with the discrepancy between references and their corresponding content, underscore the importance of critically evaluating and fact-checking ChatGPT's output before incorporating it into any research manuscripts or grant proposals.[20,22,30,99,112]

4.2.3. Misinformation and fraud. Acknowledging the substantial risk of research fraud associated with using the ChatGPT is imperative. This includes concerns such as ghostwriting, where ChatGPT may be used to generate research papers or content without proper attribution, potentially leading to academic dishonesty. Additionally, there is a looming threat of falsified or fake research materials being produced using ChatGPT, which can undermine the integrity of scholarly work and scientific progress. Furthermore, there is a parallel risk of ChatGPT inadvertently generating misinformation or disinformation that can contribute to the spread of inaccuracies and unfounded claims. This, in turn, can lead to the proliferation of infodemics, where false or misleading information spreads rapidly, posing significant challenges to public understanding and decision-making. These potential risks underscore the critical need for responsible and vigilant use of ChatGPT in research and communication contexts.[33,97,104,112–117]

4.2.4. Limited data availability. It is crucial to recognize that ChatGPT's knowledge is constrained by the data it was trained on, which only extends until 2021. Consequently, ChatGPT should not be relied upon as a dependable source for current and up-to-date literature reviews or the latest developments in various fields.[47,118] However, it can still be a valuable tool

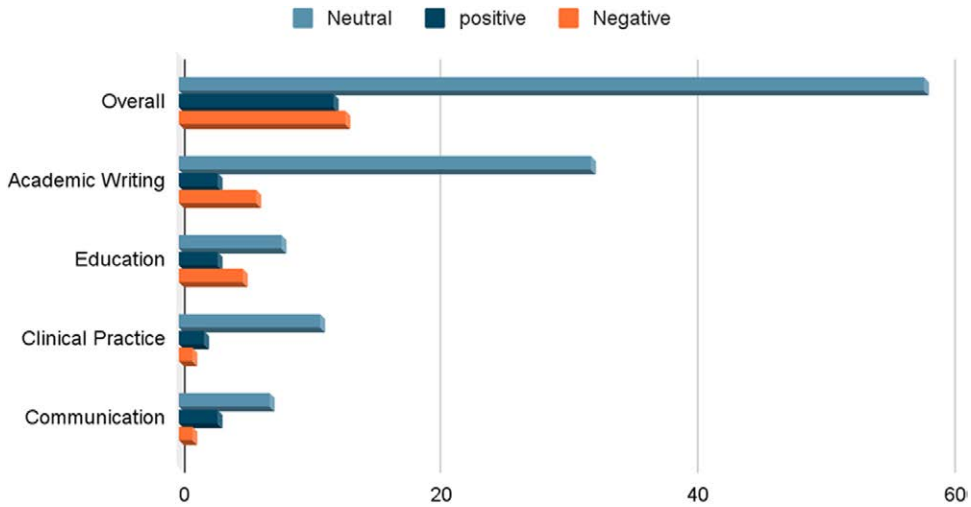

Figure 3. 58 studies presented both positive and negative, 13 presented only negative, and 12 shared only positive findings in their results.

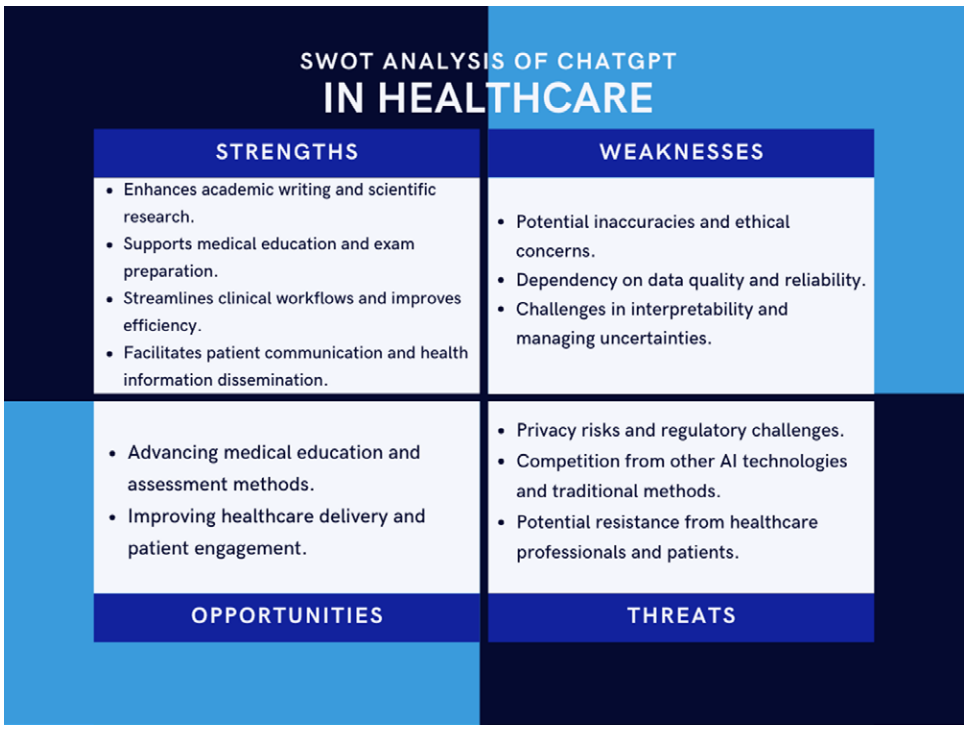

Figure 4. SWOT Analysis of ChatGPT in Healthcare.

for structuring and organizing existing literature, provided it is supplemented with trustworthy and contemporary references. In this capacity, ChatGPT can help researchers and scholars create well-structured summaries and overviews of existing knowledge while ensuring that the information presented is based on the most recent and credible sources available.[34,37]

4.3. Medical education and examination

Several trials have demonstrated the capability of ChatGPT to both take and administer examinations, raising questions about the need to reevaluate and update existing assessment tools in healthcare education. This arises in light of ChatGPT's proficiency in passing recognized exams such as the USMLE and the potential misuse of ChatGPT, which could lead to academic dishonesty. ChatGPT has shown promise in successfully completing practice exams for the USMLE and UK licensing exams.[10,58,66,119–121] Furthermore, it has demonstrated competence in various medical fields, including neurosurgery, pathology, gynecology, obstetrics, radiology interpretation, radiology board examinations, ophthalmology, life support examinations conducted by the American Association, and parasitology examinations.[59,60,62,64,66,69] These achievements warrant a reconsideration of assessment methods in healthcare education to account for the capabilities and potential misuse of ChatGPT. Upon closer examination, we uncovered some intriguing insights. ChatGPT exhibited the ability to pass exams, achieving scores within the 60-70% range, primarily for simpler and frequently encountered questions. However, as the questions became more complex and introduced novel scenarios, ChatGPT's success rate significantly declined. While it often provided correct answers, it was notable that its explanations were often incorrect, and instances of hallucinatory responses were frequently reported in various cases.[58,60,65,67]

4.4. ChatGPT's role in healthcare practice, potential challenges and areas of concerns

From a healthcare practice perspective, the current assessment reveals a cautious yet optimistic sentiment regarding the potential applications of ChatGPT. ChatGPT demonstrates the capacity to streamline clinical workflows, offering the promise of cost savings and enhanced efficiency in healthcare delivery.[104,122–124] This promise is exemplified in a recent study by Patel and Lam, which underscores the ability of ChatGPT to produce efficient discharge summaries, reducing the documentation burden in healthcare settings.[125] Furthermore, in healthcare practice, ChatGPT and other LLMs have the potential to revolutionize diagnostics, disease risk prediction, outcome forecasting, and drug discovery, thus advancing translational research in several areas.[126–128]

Apart from this, AI on a broader extent, has been able to assist in the field of radiology at various distinct levels. In computed tomography (CT), for instance, AI computed models can assist in CT positioning and automatically create different views aiding in accurate post-processing of images.[129]This can reduce the likelihood of radio-diagnostic errors from manual operation. Similarly, a study by Bandla et al[130] highlights the potential of AI in detecting subtle, accurate, and specific radiographic abnormalities, allowing for the precise identification and diagnosis of the various different diseases and conditions. More specifically, the AI tool ChatGPT can be utilized in radiological educational training, report generation, data analysis, patient communication and clinical radiodiagnosis.[131] Further, ChatGPT exhibits moderate accuracy in determining the necessary imaging steps for breast cancer screening and evaluating breast pain, offering a promising application for aiding radiology-based decision-making processes.[132]

In healthcare settings, ChatGPT has the potential to refine personalized medicine and enhance health literacy by providing easily accessible and understandable health information to the general public.[133–136] It is worth noting that while ChatGPT offers valuable insights, its responses underscore the importance of consulting healthcare providers and other reliable sources in specific situations.[90,104,137]

ChatGPT depends heavily on data, and its most significant drawback in medical practice is its susceptibility to bias. Nearly all studies have highlighted that ChatGPT's responses to prompts exhibit a concerning level of bias. There are instances in which ChatGPT tends to exaggerate findings. For instance, when a patient reports a mild ache, ChatGPT might suggest the possibility of a neoplasm, causing unnecessary anxiety in patients without a relevant medical history. This underscores the importance of integrating AI in medical practice, such as platforms like UpToDate, which are widely utilized globally to ensure reliable and unbiased healthcare guidance. Moreover, ChatGPT demonstrates its usefulness in circumstances where human intelligence may waver. For example, owing to its impressive recall memory, it excels in tasks such as recalling specific genes and prescribing appropriate antibiotics based on the identified organism. In addition, ChatGPT's shortcomings include interpretability, repeatability, and uncertainty management. These restrictions present serious issues, particularly in healthcare settings and research.[117,128,135] Given the variances found across distinct populations in many health-related parameters, the lack of openness and uncertainty surrounding the data sources used in ChatGPT training has become a key challenge in healthcare contexts.[132] The repeatability issue across multiple runs of ChatGPT prompts is particularly important, indicating a significant restriction in healthcare practice.[126] Additional concerns related to ChatGPT's implementation in healthcare pertain to the absence of personalized and emotionally sensitive perspectives required for effective healthcare delivery and research.[133,138] Nevertheless, there has been an instance where ChatGPT has successfully replicated empathetic responses, as documented in a preprint focused on hepatic diseases.[136] Moreover, the inherent design of ChatGPT restricts its input capabilities to text, excluding images, audio, video, and other data. While strong in certain contexts, this design limitation poses a substantial drawback in practical medicine, where radiological images and thorough history and examination play pivotal roles. Neglecting these aspects could prevent ChatGPT from becoming a highly effective tool in clinical practice.

4.5. Utilizing ChatGPT for interactions with patients

Employing ChatGPT as a means of patient communication represents a valuable resource for healthcare professionals seeking to enhance the quality of care and streamline information-sharing. By leveraging this technology, healthcare professionals can provide clear and understandable explanations to patients about their medical conditions, treatment options, and health-related questions. ChatGPT facilitates more efficient and accessible interactions, offers patients a platform to pose questions, seek guidance, and obtain tailored responses, and fosters heightened patient satisfaction and engagement throughout their healthcare journey.[85,86,88,92]

While a range of studies have explored the utility of ChatGPT, the results have exhibited variability in certain aspects. Notably, there is consistency in its efficiency in describing suitable drug options or prescribing medications for headaches. Nonetheless, it is crucial to acknowledge some areas of concern, such as the need for up-to-date data, the potential presence of inaccurate information, and the possibility of hallucinatory responses, all of which can introduce a degree of bias into interactions.[87,90,92,93] It is important to note that several alternative platforms, such as UpToDate, offer more efficient prescription services. However, they may lag behind ChatGPT in terms of their communication capabilities, highlighting the unique advantages and trade-offs associated with different tools in the healthcare landscape.

4.6. AI, ChatGPT application in pharmacovigilance industry

AI has a crucial role in transforming the pharmacovigilance industry. AI models like ChatGPT provide powerful solutions to process diverse data sources, such as clinical trials, electronic health records, social media, and spontaneous reports.[139,140] For instance, ChatGPT can automate the analysis of adverse drug reactions reported in textual formats, enabling rapid identification of potential safety issues and prompt regulatory actions. This enhances efficiency and accuracy in pharmacovigilance, leading to improved patient safety and public health outcomes.[141]

AI tools like ChatGPT can improve pharmacovigilance by monitoring various data sources to identify emerging safety signals.[142] This enables regulatory authorities and pharmaceutical companies to address safety concerns and enhance healthcare quality. AI-driven predictive modeling can forecast potential safety issues, allowing stakeholders to implement preventive measures and mitigate risks. As AI evolves, it will play an indispensable role in enhancing drug safety surveillance and risk management, ushering in a new era of proactive and data-driven pharmacovigilance practices.[143,144]

4.7. Healthcare industry before and after the use of ChatGPT

The healthcare industry has experienced significant transformations with the integration of AI technologies such as ChatGPT. These advancements have improved patient care, diagnosis, treatment, and administration by addressing challenges related to resource constraints, fragmented data management systems, and inefficient decision-making processes. The adoption of AI in healthcare has led to more efficient, data-driven, and patient-centric practices.[94,145,146]

Before ChatGPT, medical professionals primarily relied on manual processes for tasks such as documentation, communication, and information retrieval. ChatGPT's advanced natural language processing capabilities enable task automation, streamlined documentation, and improved patient communication.[94] ChatGPT can generate clinical notes, answer patient questions, and provide evidence-based suggestions, saving time and enhancing productivity in healthcare settings. ChatGPT has transformed medical decision-making by providing healthcare professionals with real-time access to vast amounts of medical knowledge and research literature, overcoming the challenge of staying updated with the latest medical research and guidelines.[147,148] ChatGPT's ability to sift through vast datasets and deliver evidence-based insights empowers clinicians to make more informed decisions. Additionally, ChatGPT's predictive analytics capabilities enable proactive identification of potential health risks, early detection of diseases, and personalized treatment recommendations based on individual patient data, driving innovation across various domains of healthcare delivery and management.

4.8. AI applications in radiodiagnosis

AI applications like ChatGPT and computer-aided detection (CAD) systems are transforming radiodiagnosis by enhancing how medical imaging is interpreted and analyzed in patient care.[149–152] CAD systems use AI algorithms to assist radiologists in identifying abnormalities and potential issues in medical images, including X-rays, CT scans, and magnetic resonance imagings. By serving as a second pair of eyes, CAD systems improve the accuracy and speed of radiological interpretations by highlighting subtle features or anomalies that may be missed during manual analysis.[152]

AI-driven image segmentation in radiodiagnosis partitions medical images into meaningful regions for quantitative analysis and treatment planning. It delineates organs, tumors, blood vessels, and structures enabling precise measurements, volumetric assessments, and treatment simulations.[153,154] AI-driven image reconstruction enhances medical imaging by improving image quality, reducing noise, and increasing spatial resolution in various modalities, enabling clinicians to obtain superior images and minimize radiation exposure or scan time for patients. AI utilization in radiology leads to accurate diagnoses, better patient care, and accelerated medical research and innovation in radiodiagnosis.

5. Limitations

While our study yielded significant results, it is essential to acknowledge and address some limitations that should be the focus of future research. Most studies evaluated ChatGPT's performance based on its initial response, even though generating a new response could yield a different answer. Future studies should focus on generating multiple responses from ChatGPT for the same prompt and then analyzing the answers. Moreover, the quality of responses generated by ChatGPT depends on the quality of the prompts; hence, this may also lead to variability in outcomes and the overall effectiveness of the AI system in different scenarios.

Another limitation of our study is the exclusion of non-English articles. Lastly, the rapid proliferation of literature pertaining to ChatGPT applications and associated risks necessitate further research and reviews, particularly considering that the search for this review was concluded on May 17, 2023.

6. Conclusion

In conclusion, this systematic review illuminates ChatGPT's significant impact on medical science and healthcare. Across various applications such as academic writing, medical education, clinical practice, and patient communication, ChatGPT demonstrates potential benefits including improved productivity, enhanced educational tools, and streamlined clinical workflows. However, critical considerations such as the risk of misinformation, ethical implications, and transparency issues underscore the need for cautious implementation and ongoing research. As AI technology evolves, future advancements beyond ChatGPT-4 will require continued evaluation and ethical guidelines to maximize benefits while mitigating risks. Ultimately, ChatGPT stands poised as a transformative tool in shaping the future of healthcare and scientific research, highlighting the importance of responsible deployment and adaptation to harness its full potential effectively.

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