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Systematic Review
Intersection of ChatGPT and Pharmacology: A Bibliometric Assessment of Research Trends and Key Themes

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Abstract

Background and Objective: The rapid evolution of Artificial Intelligence (AI) technologies has profoundly impacted various scientific fields, including pharmacology. The ChatGPT, an advanced language model, has become a valuable tool in this domain, enhancing productivity and innovation. This study aims to investigate the integration of advanced AI technologies, particularly ChatGPT, into pharmacological research through a comprehensive bibliometric analysis. **Materials and Methods:** A comprehensive search was conducted in the Scopus database, using specific keywords related to ChatGPT, AI and pharmacology. The search yielded 274 relevant articles. The selected articles were analyzed using bibliometric tools to construct co-authorship and keyword co-occurrence networks, highlighting key research areas and trends. **Results:** The bibliometric analysis identified five research clusters: Experimental and Molecular Pharmacology, AI and Computational Approaches, Clinical and Human Studies, Veterinary and Animal Science and Chemical and Screening Methods. Keyword co-occurrence mapping highlighted prominent themes like 'machine learning', 'gene expression' and 'clinical pharmacology'. A dramatic increase in publications was observed, particularly from 2020 to 2024, reflecting the growing integration of AI in pharmacological research. **Conclusion:** The findings emphasize the importance of addressing ethical considerations and fostering collaborations between AI experts and pharmacologists to ensure responsible and innovative advancements in pharmacology and avoid the concerns raised by the use of AI tools such as ChatGPT.

Key words: Artificial intelligence, ChatGPT, pharmacology, bibliometric analysis, drug discovery, co-authorship networks, keyword co-occurrence, research trends, AI applications

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The rapid evolution of AI technologies has impacted various scientific fields, bringing about significant advancements and novel methodologies[1,2]. In healthcare, AI has supported diagnostics and treatment planning[3]. Machine learning algorithms analyze vast amounts of medical data to predict disease outbreaks, customize patient treatment plans and identify potential drug candidates[4]. The AI-driven imaging techniques have enhanced the accuracy of detecting diseases such as cancer, which helps in decisions driven by radiologists[5].

The ChatGPT, as an advanced language model, has become a valuable tool across various scientific disciplines including medical sciences[6]. The ChatGPT is a sophisticated language model that utilizes deep learning methods to generate responses that resemble human communication when given natural language prompts[7]. The versatility and accessibility of ChatGPT enhance productivity and innovation, making it an indispensable asset in modern scientific applications.

Bibliometric analysis is a quantitative method used to assess the impact and trends of scientific research through the systematic examination of publications and their citations[8]. This method involves the use of various metrics, such as the influence of research articles, journals, authors and institutions[9]. The importance of bibliometric analysis lies in its ability to provide insights into the development and dissemination of knowledge within a particular field[10]. It helps identify influential research, emerging trends and collaborative networks, thereby guiding researchers, funding agencies and policymakers in making informed decisions about research directions, funding allocations and academic collaborations.

This study aims to investigate the integration of advanced AI technologies, particularly ChatGPT, into pharmacological research through a bibliometric analysis. By examining a broad spectrum of publications from the Scopus database, the study identifies key research themes, collaborative networks and the evolution of topics in this domain. The analysis focuses on constructing co-authorship and keyword co-occurrence networks to highlight prominent research areas, such as experimental pharmacology, AI applications, clinical studies, veterinary science and chemical screening methods. Additionally, the study evaluates publication trends and the distribution of research across various scientific disciplines, offering insights into the rapid growth and significant impact of AI technologies on pharmacological research and practice. Finally, the study will identify the emerging themes in this domain.

MATERIALS AND METHODS

Database and data collection: On June 17th, 2024, a comprehensive search was conducted in the Scopus database to identify articles related to the role of ChatGPT in pharmacology. The search strings used were designed to capture a broad spectrum of relevant studies. The following string was used in the search prompt (TITLE-ABS-KEY (ChatGPT) or TITLE-ABS-KEY (artificial and intelligence) or TITLE-ABS-KEY (AI) and TITLE-ABS-KEY (pharmacology)) and (EXCLUDE (DOCTYPE, "er")) and (LIMIT-TO (LANGUAGE, "English")). This search strategy yielded 274 articles that contained these terms in their title, abstract or keywords.

Search strategy and screening: The search strategy for the bibliometric analysis on ChatGPT, Artificial Intelligence (AI) and pharmacology began with a clear topic selection. The primary focus was to investigate the intersection of these technologies and pharmacology, ensuring that the research captures the latest developments and trends in this domain.

In terms of scope and coverage, the search was conducted using the Scopus database. The search fields included the article title, abstract and keywords to capture a broad yet specific range of studies. Importantly, no time frame limitations were applied, allowing for the inclusion of all relevant articles irrespective of their publication date. The search was restricted to articles written in English and published to maintain consistency and accessibility. All document types were initially included, but erratum entries were excluded to avoid duplicates.

On June 17th, 2024, the search was executed, yielding a total of 305 records. Each record was then screened to ensure it met the inclusion criteria. Records that did not meet the language requirement or were identified as errata were removed. Specifically, one erratum record and 30 non-English language records were excluded from the dataset. Finally, after the screening and removal process, 274 records were deemed suitable for inclusion in the bibliometric analysis (Fig. 1).

Software and data handling: The complete records of the selected articles were downloaded from the Scopus database and imported into bibliometric analysis software tools, specifically VOSviewer software[11].

At first, the records were saved in a format compatible with VOSviewer, CSV and RIS file. This file contained essential bibliometric information such as titles, abstracts, keywords, author names and affiliations. Once the data was prepared, it was imported into VOSviewer.

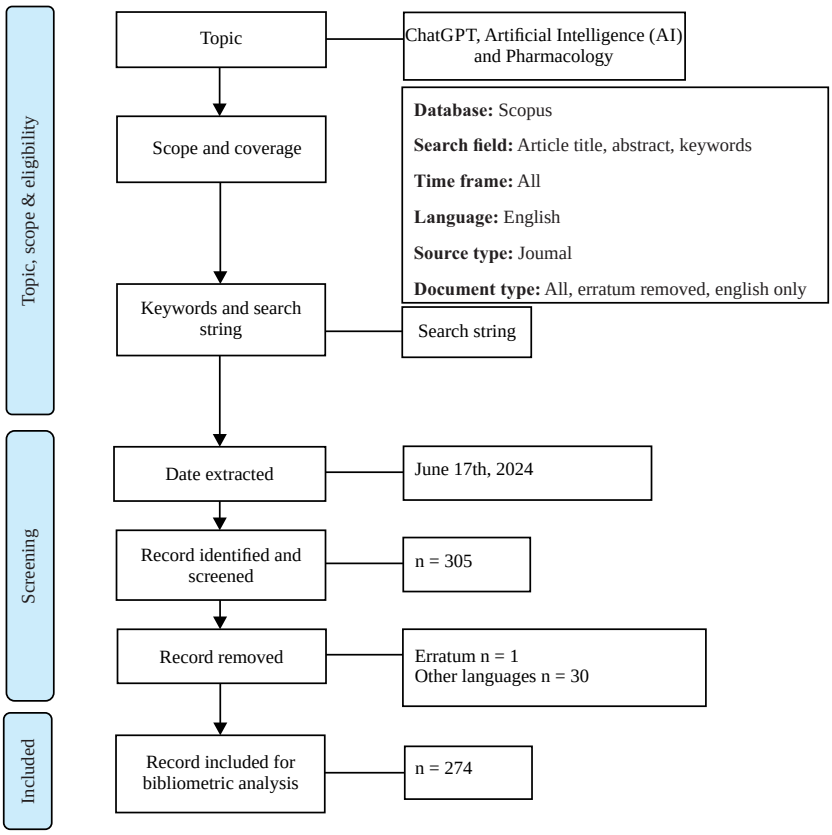

Fig. 1: PRISMA flow chart of articles processing and screening

Constructing bibliometric networks: The VOSviewer was used to construct various bibliometric networks. The analysis focused on co-authorship and keywords co-occurrence, networks. The co-authorship networks helped identify collaborative relationships among researchers and institutions. The co-occurrence networks, based on keywords, revealed the main research topics and trends.

Visualization and interpretation: Network visualization was displayed as nodes and their relationships as lines, with the distance between nodes indicating the strength of their relationship. Overlay visualization allowed the mapping of additional attributes, such as publication year, onto the network, providing temporal insights.

RESULTS

Analysis of keywords clusters: The keywords co-occurrence map reveals several distinct clusters representing different themes and areas of focus within the research on ChatGPT, AI and pharmacology. The keywords co-occurrence analysis was set to a minimum of 10 to capture the most prominent and effective analysis. Of 4617 hits, 86 keywords met these criteria, which generated five different clusters (Fig. 2).

Cluster 1

Experimental and molecular pharmacology: Cluster 1 primarily focuses on experimental pharmacology and molecular studies, involving various *in vitro* and *in vivo* experiments. Keywords such as 'animal experiment,' 'animal model,' and 'animal tissue' indicate significant research using animal subjects to understand disease mechanisms and evaluate drug effects. Molecular-level studies are highlighted by keywords like 'apoptosis', 'cell proliferation' and 'gene expression', which are essential for understanding cellular responses to pharmacological interventions. The presence of keywords like 'molecular docking' and 'signal transduction' suggests substantial research into the molecular mechanisms of drug action and the use of computational modeling to predict drug interactions.

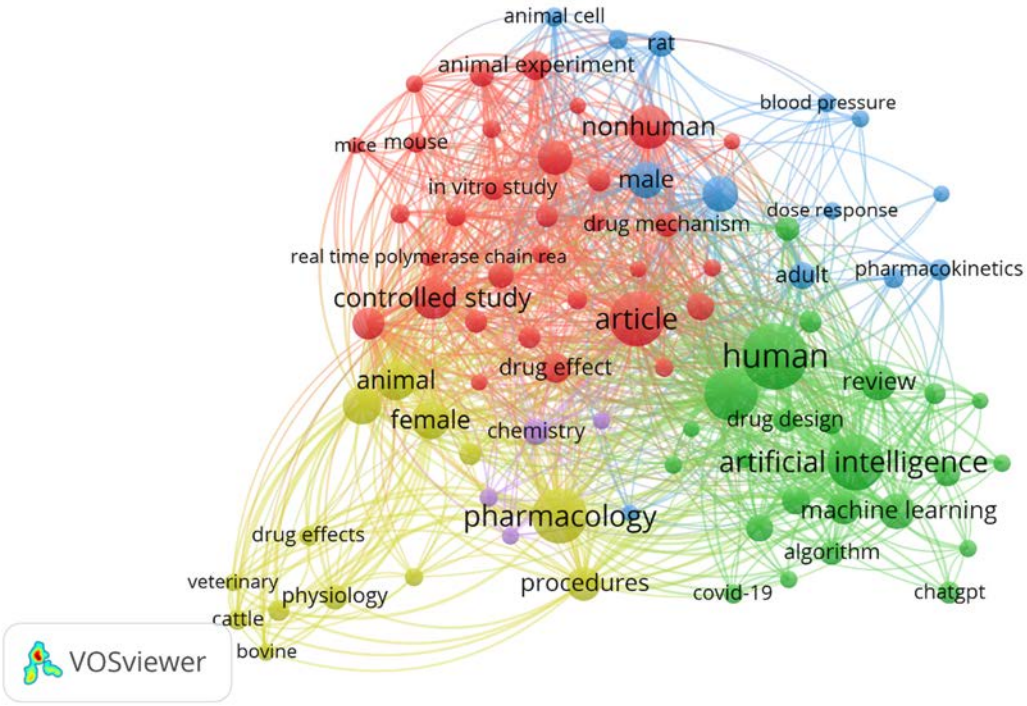

Fig. 2: Keywords co-occurrence map highlighting different research themes

Cluster 2

AI and computational approaches: Cluster 2 centers around the application of AI and computational tools in pharmacology. This cluster includes keywords such as'algorithm', 'artificial intelligence', 'machine learning' and 'deep learning', indicating a strong emphasis on leveraging advanced computational techniques to enhance drug discovery and development. The presence of 'ChatGPT' and 'natural language processing' reflects the growing use of AI language models for analyzing scientific literature, generating hypotheses and facilitating drug discovery processes. Keywords like 'drug design', 'drug development' and 'drug discovery' highlight the application of these computational approaches in identifying and optimizing new therapeutic compounds, demonstrating the integration of AI in modern pharmacological research.

Cluster 3

Clinical and human studies: Cluster 3 highlights research focused on human subjects and clinical pharmacology. Keywords such as 'adult', 'male', 'female' and 'human experiment' indicate a focus on clinical trials and studies involving human participants. This cluster also includes keywords like 'clinical pharmacology', 'pharmacodynamics' and 'pharmacokinetics', suggesting detailed investigations into the effects, mechanisms and dynamics of drugs in human systems. The inclusion of keywords like 'major clinical study' and 'oral drug administration' emphasizes the translation of pharmacological research from experimental models to clinical applications.

Cluster 4

Veterinary and animal science: Cluster 4 focuses on veterinary pharmacology and animal science. Keywords such as 'animal', 'bovine', 'cattle' and 'veterinary' indicate research aimed at understanding drug effects and treatments in livestock and other animals. The inclusion of 'genetics' and 'physiology' suggests studies on the genetic and physiological aspects of animals in response to pharmacological interventions.

Cluster 5

Chemical and screening methods: Cluster 5 is smaller but focuses on the chemical aspects of drug discovery and screening methods. Keywords like 'chemistry', 'drug screening', 'molecular library' and 'small molecule libraries' indicate research on the chemical properties of compounds and the processes used to identify potential therapeutic agents.

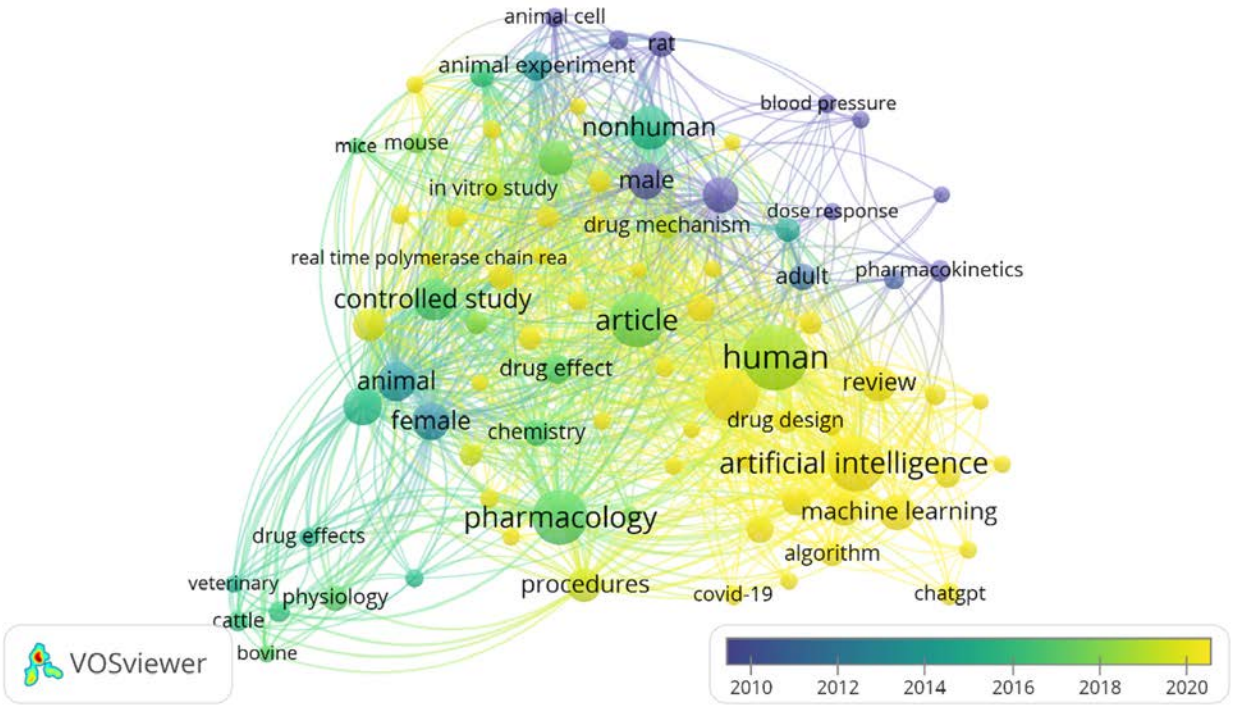

Fig. 3: Overlay representation of keywords displaying different themes and areas of research focus

The average publication year for each keyword provides insights into the temporal evolution of research topics. Recent keywords such as 'artificial intelligence', 'machine learning', 'ChatGPT' and 'natural language processing' indicate emerging trends in applying AI technologies to pharmacology. In contrast, foundational topics like 'controlled study', 'drug effect' and 'pharmacology' have been consistently important over time, reflecting their established significance in the field.

Analysis of keywords overlay: The keywords overlay visualization from the VOSviewer map provides insights into the evolution of research topics in ChatGPT, AI and pharmacology. The color-coded timeline highlights how research focus has shifted over the past decade, with recent trends indicated by yellow and light green shades, while established themes are shown in green and blue (Fig. 3).

Established themes: Established research themes from 2010 to 2017 are represented by green and blue keywords. Foundational topics such as 'pharmacology', 'drug effect', 'drug mechanism' and 'controlled study' remain central to the field, reflecting ongoing efforts to understand drug interactions and therapeutic effects. The focus on clinical studies is evident from keywords like 'human', 'clinical pharmacology' and 'controlled study', highlighting the importance of translating experimental findings into clinical applications to ensure drug efficacy and safety. The consistent presence of keywords related to experimental models, such as 'animal experiment', 'animal model' and *'in vitro* study', underscores the vital role of preclinical research in drug development.

Specialized research areas: Several keywords represent specialized research areas that have focused attention. Research in veterinary and animal science is indicated by keywords like 'veterinary', 'cattle' and 'bovine', emphasizing the importance of understanding drug effects in animals and improving veterinary practices. Molecular and cellular studies are highlighted by keywords such as 'apoptosis', 'cell proliferation', 'gene expression' and 'molecular docking', which are essential for uncovering the mechanisms of drug action and identifying therapeutic targets. Chemical screening and drug discovery methods are also well-represented with keywords like 'chemistry', 'drug screening', 'molecular library' and 'small molecule libraries.'

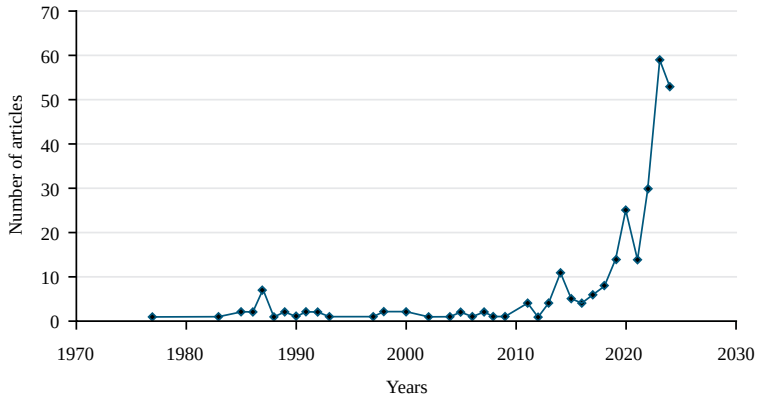

Fig. 4: Number of publications representing the research on ChatGPT, Artificial Intelligence (AI) and pharmacology

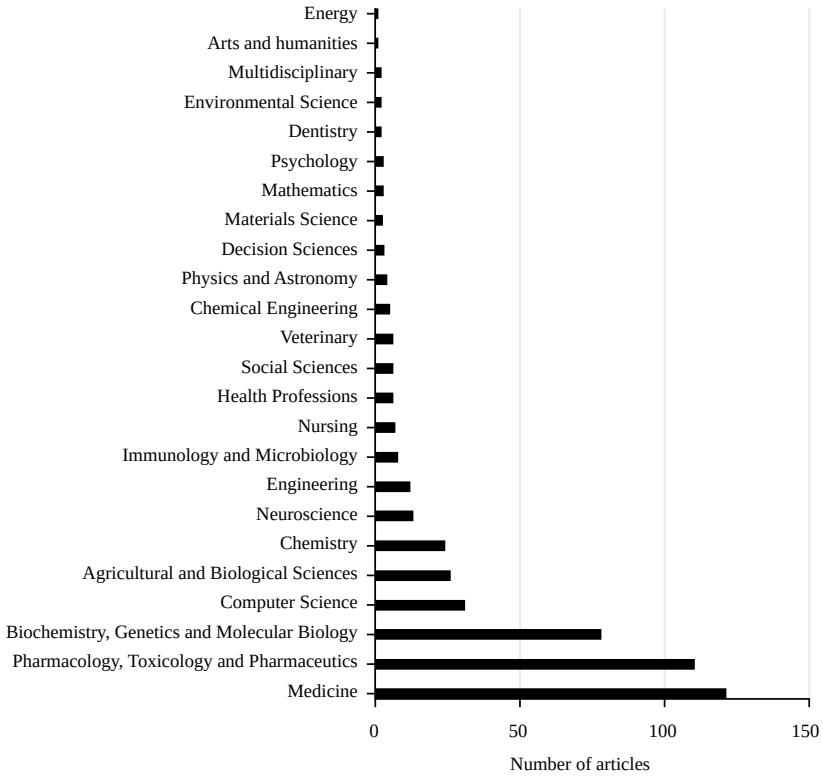

Fig. 5: Scientific disciplines involve the research on ChatGPT, Artificial Intelligence (AI) and pharmacology

Recent trends: In recent years (2018-2020), there has been a significant surge in research related to artificial intelligence, as indicated by keywords such as 'Artificial Intelligence', 'machine learning' and 'algorithm'. These keywords highlight the integration of advanced computational methods into pharmacology, particularly for enhancing drug discovery and development processes. The emergence of 'ChatGPT' and 'natural language processing' underscores the growing interest in AI-driven language models to facilitate literature analysis and hypothesis generation.

Publications trend: The analysis of the yearly output of publications related to ChatGPT, AI and pharmacology from 1977 to 2024 reveals significant trends and shifts in research focus (Fig. 4). In the earlier years, from 1977 to around 2013, the publication activity was relatively sparse and sporadic. This period saw occasional peaks, such as in 1987 with seven publications, but generally, the research output remained low. This indicates that AI and related technologies were not yet prominently integrated into pharmacological research during this time.

A noticeable increase in publication activity began around 2014, marking the mid-past decade as a period of gradual growth. The number of publications ranged from 4 to 14 per year between 2014 and 2019, reflecting a rising interest in the intersection of AI and pharmacology. This period set the foundation for more significant growth, as researchers began to explore the potential applications of AI technologies in drug discovery, development and other pharmacological processes.

The most dramatic increase in research activity is observed in the last five years, from 2020 to 2024. The number of publications surged significantly, with 25 publications in 2020, 14 in 2021 (transient drop), 30 in 2022, 59 in 2023 and 53 in 2024. This sharp rise reflects the accelerating focus on AI technologies, driven by advancements in machine learning, data analysis and natural language processing.

The exceptionally high number of publications in 2024, which stands at 53 by June 17th alone, is a remarkable indicator of the rapidly increasing interest and activity in the domains of ChatGPT, AI and pharmacology. This surge within just the first half of the year suggests that 2024 is poised to surpass previous years in terms of research output, reflecting an intensified focus on ChatGPT and AI technologies in pharmacological research.

Scientific disciplines

Analysis of subject area distribution: The distribution of publications across various subject areas provides a comprehensive overview of the interdisciplinary nature of research involving ChatGPT, AI and pharmacology (Fig. 5).

Dominant fields: Medicine is the leading subject area (121 publications), reflecting the significant impact of AI technologies on medical research and practice. Pharmacology, toxicology and pharmaceutics scored 110 publications. The high number of publications underscores the importance of integrating AI to accelerate pharmacological research and development. The field of biochemistry, genetics and molecular biology scored 78 publications.

The presence of computer science with 31 publications highlights the foundational role of this discipline in advancing AI technologies. Additionally, agricultural and biological sciences (26 publications) and chemistry (24 publications) reflect AI's role in optimizing agricultural practices and advancing chemical research, respectively.

Specialized areas such as neuroscience, engineering, immunology, microbiology and others illustrate the wide-ranging impact of AI. Neuroscience, with 13 publications, benefits from AI in studying brain function and neurological disorders. Engineering's 12 publications indicate AI's role in developing medical devices and diagnostic tools. Immunology and microbiology with 8 publications, leverage AI for understanding immune responses and pathogen behavior, essential for vaccine and treatment development.

DISCUSSION

This study conducted a comprehensive bibliometric analysis to explore the integration of AI technologies, particularly ChatGPT, in pharmacological research. The analysis revealed five distinct research clusters: Experimental and Molecular Pharmacology, AI and Computational Approaches, Clinical and Human Studies, Veterinary and Animal Science and Chemical and Screening Methods. When comparing these findings with previous literature, both consistencies and novelties can be observed. The analysis of keyword trends reveals the evolving focus of research over time. Initially, foundational topics such as pharmacology, drug effects and clinical studies dominated the field. However, in recent years, there has been a marked increase in the use of AI-related keywords such as machine learning, natural language processing and ChatGPT. The use of AI, particularly through tools like ChatGPT, has enhanced the capabilities of researchers in analyzing large datasets, predicting outcomes and generating hypotheses[7]. This has streamlined various processes in pharmacology, from drug discovery and development to clinical trials and personalized medicine[4,12]. For instance, the emphasis on clinical pharmacology in our study, particularly in human studies including personalized therapy, complements findings from Liu *et al.*[13] and Zahra *et al.*[14], highlighting AI's potential to enhance clinical trial processes and personalized medicine. In addition, the prominent role of AI in molecular docking and drug discovery studies aligns with the report of Chakraborty *et al.*[15], who emphasized AI's utility in molecular-level drug research. Similarly, the identified trends in machine learning applications resonate with broader AI adoption trends noted by Daher *et al.*[5]. However, our study contributes to emerging topics by offering a focused analysis on pharmacology, highlighting specific areas like AI's role in clinical trials and veterinary sciences. The study highlights significant research in clinical pharmacology, emphasizing the application of AI in human studies and veterinary science, focusing on animal models and treatments[16,17].

The recent shift in topics toward AI agreed with the recent findings of AI technologies in pharmacological research and the ongoing exploration of new AI applications in pharmacy and pharmacology[18,19]. The overlay visualization provided a clear map, showing the transition from traditional pharmacological methods to advanced AI-driven techniques. The distribution of publications across different scientific disciplines further illustrates the interdisciplinary nature of AI applications in pharmacology. Medicine and pharmacology are the leading fields, demonstrating the direct impact of AI on healthcare and drug development. However, the significant presence of computer science, biochemistry and molecular biology indicates the foundational role of these disciplines in developing and applying AI technologies. Additionally, the involvement of fields such as neuroscience, engineering and veterinary science highlights the widespread adoption of AI in various biological and medical research areas. All these fields were benefited from these technological advances[4,20,21].

The inclusion and rise of ChatGPT in pharmacological research, while promising, present several precautions that must be addressed to adhere to ethical standards. One significant concern is the potential for bias in AI-generated results, stemming from biases present in the training data, which can lead to skewed or inaccurate conclusions[22]. Additionally, the use of AI models like ChatGPT raises issues of data privacy and security[23]. Ensuring transparency in AI methodologies and maintaining robust ethical guidelines are essential to mitigate these risks.

This study excels in its comprehensive scope, drawing on an extensive dataset from the Scopus database to cover a wide array of publications. Additionally, the study's focus on publication trends highlights the rapid growth and increasing significance of AI technologies in the field over the past decade. Despite its strengths, the study has certain limitations. Its reliance solely on the Scopus database, while comprehensive, may not capture all relevant publications as grey publications, particularly those in non-English languages. Moreover, bibliometric analysis, although powerful, provides a static snapshot of research trends and collaborations. It may not fully capture the dynamic and rapidly evolving nature of AI applications in pharmacology, necessitating continuous updates and follow-up studies.

CONCLUSION

This study underscores the intersection of artificial intelligence, particularly ChatGPT, in the pharmacological domain, highlighting key research themes, collaborative networks and temporal trends through comprehensive bibliometric analysis. The findings reveal significant and growing records, especially in recent years. Addressing ethical considerations and potential biases in AI-driven research, along with fostering collaborations between AI experts and pharmacologists, will be important for ensuring responsible, innovative and equitable advancements in pharmacological domains.

SIGNIFICANCE STATEMENT

This study illuminates the profound impact of AI technologies, particularly ChatGPT, on pharmacological research. By conducting a comprehensive bibliometric analysis, it identifies key research trends and collaborative networks, showing the expanding role of AI in advancing pharmacology domains. The findings underscore the transformative potential of AI in enhancing productivity and innovation within pharmacology, providing valuable insights for researchers, funding agencies and policymakers.

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