Editorial
Male reproductive health and infertility

pISSN: 2287-4208 / eISSN: 2287-4690
World J Mens Health Published online Mar 27, 2025
https://doi.org/10.5534/wjmh.240007

The World Journal of MEN's HEALTH

Artificial Intelligence in Scientific Writing: Balancing Innovation and Efficiency with Integrity: Perspectives and Position Statements of Global Andrology Forum Expert Group

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INTRODUCTION

1. Artificial intelligence: new frontier

Artificial intelligence (AI) is a new frontier that is being increasingly integrated into almost every facet of today's human life. Over the past decade, the applications of AI technologies have grown tremendously and rapidly in scientific research and publications. AI has become a transformative tool helping scientists to conduct comprehensive literature reviews, create hypotheses, design experiments, generate text with sophisticated editing and paraphrasing, collect and interpret large datasets, and gain insights that might not be realized using traditional research methods [1].

Received: Jan 5, 2025 **Revised:** Jan 15, 2025 **Accepted:** Jan 21, 2025 **Published online** Mar 27, 2025
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The researchers contributing to this publication are members of the Global Andrology Forum (GAF), based in Moreland Hills, OH, USA. GAF operates under the Global Andrology Foundation, a non-profit organization registered in Innsbruck, Austria.

Further, some AI tools are instrumental in generating codes for statistical analysis [2]. preparing graphs, and interpreting results. AI tasks can be accomplished using technologies based on natural language processing for communications between humans and computers combined with neural network programming known as large language models (LLMs). However, AI is not without limitations, and it is vital to recognize the potential risks associated with AI use and take appropriate precautions to mitigate such risks [3].

Like any innovative, transformative technology—despite its obvious advantages—the challenge is to learn how to use AI effectively and ethically. As the scientific community navigates this digital revolution, it is decisive to balance AI's advantages and limitations and maintain the integrity and authenticity of academic writing.

2. Objectives and the Global Andrology Forum's position statements

In this article, we elaborate on the use of AI technologies in scientific writing and publications and address their advantages and limitations. We provide the Global Andrology Forum (GAF) expert group perspectives and position statements and suggest remedies to mitigate AI limitations, aiming to encourage and ensure the appropriate use of AI.

AI IN ACTION

1. Example of AI-generated text

This example demonstrates how surprisingly quickly—within seconds—the AI could generate a well-formulated summary, using Microsoft Copilot, after a request to write about 150 words on the "future of AI in scientific writing and publishing":

> The future of AI in scientific writing and publishing is poised to revolutionize the field. AI tools are increasingly being used to assist researchers in drafting manuscripts, conducting literature reviews, and even generating hypotheses. These tools can analyze vast amounts of data quickly, identify relevant studies, and suggest citations, significantly speeding up the writing process. Moreover, AI can help detect plagiarism, ensure the originality of the content, and improve the overall quality of manuscripts through advanced grammar and style checks. AI can streamline the peer review process in publishing by identifying suitable reviewers and flagging potential conflicts of interest. It can also assist in the initial screening of submissions, ensuring that only high-quality papers are sent for review. As AI continues to evolve, it is expected to enhance transparency, reduce biases, and increase the efficiency of scientific communication, ultimately accelerating the pace of scientific discovery.

2. Case studies and success stories

Several case studies have showcased the ability of AI to generate plausible scientific manuscripts in medicine while emphasizing the need for careful human oversight [4]. For example, "ChatGPT" has emerged as a potentially revolutionary tool for academic writing, increasing the efficiency of producing high-quality research papers. AI tools like "Grammarly" have been demonstrated to significantly improve grammar, structure, and overall readability in scientific writing [5]. Besides, case studies of paraphrasing AI tools such as "QuillBot" and "Paraphrase Tool" reported advantages, including speed and ability to deal with large volumes of text, while highlighting the need for human proofreading and post-editing of the AI-generated paraphrased text [6].

AI TOOLS IN SCIENTIFIC WRITING

Several AI tools, such as chat generative pre-trained transformer (ChatGPT), Copilot, Gemini, Grammarly, and many others, are increasingly entering the daily work of writing an article. Filetti et al [7] reported a summary of the numerous available tools for AI-powered writing and bibliographic research assistance (such as EndNote, Mendeley and Zotero), as well as for data analysis and visualization (such as R packages and Python libraries) which may help make right choices when considering the use of AI for writing. Some of the popular and most important currently existing AI tools for scientific writing and their functions are presented in Table 1.

ADVANTAGES OF AI IN SCIENTIFIC WRITING

AI technologies bear significant advantages that have driven the increasing prominence of AI in the scientific realm. AI tools can help in contemporary

Table 1. List of some popular and important AI tools for scientific writing, and their functions[a]

AI tool	Category	Function	Source
Open AI ChatGPT	AI chatbot	Text generation and editing	https://chatgpt.com
Perplexity	AI chatbot	Text generation and editing	https://www.perplexity.ai
Copilot	AI chatbot	Multi functions AI tool. Also integrated into many Microsoft products such as Windows, Microsoft 365, and others	https://copilot.microsoft.com
GitHub Copilot	AI-powered code completion and assistance tool	AI editor for writing, debugging, and understanding codes	https://github.com/features/copilot
Gemini	Multimodal AI system platform. Includes chatbot features	Multiple AI functions	https://gemini.google.com
Grammarly	Specialized writing assistance	Text grammar, paraphrasing and plagiarsim tool	https://www.grammarly.com
SciNote	Specialized writing assistance	Lab management software with AI integration (NLP)	https://www.scinote.net/
DeepL Translator	Specialized writing assistance	Language translation	https://www.deepl.com/en/translator
Google Translate	Specialized writing assistance	Language translation	https://translate.google.com
iThenticate	Writing verification	Plagiarism detection	https://www.ithenticate.com
Justdone	Writing verification	Plagiarism detection	https://justdone.ai
Copyscape	Writing verification	Plagiarism detection	https://www.copyscape.com
Originality.ai	Writing verification	AI detectors	https://originality.ai/ai-checker
Scite.ai	Research and reference management	Citation manager	https://scite.ai/
Python libraries	Programming languages	Data management, calculation, graph generation, scientific computing	https://pypi.org/
R packages	Programming languages	Data management, statistical analysis and graph generation	https://cran.r-project.org/
Posit	Data analysis	Data analysis and visualization with AI integration of automated toolbox	https://posit.co/products/open-source/rstudio
MATLAB	Data analysis	Data analysis and visualization with AI integration of automated toolbox	https://www.mathworks.com/products/matlab.html
Zotero	[b]	Reference manager	https://www.zotero.org/
EndNote	[b]	Reference manager	https://endnote.com
Mendeley	[b]	Reference manager	https://www.mendeley.com
MedPalm	AI tool in medical field	Medical knowledge, diagnostics, and patient care	https://sites.research.google/med-palm/

AI: artificial intelligence, NLP: natural language processing.
[a]The authors do not endorse these applications and declare no commercial interest or affiliation with them.
[b]These software programs are not primarily AI-driven applications and do not utilize advanced AI algorithms such as machine-learning or deep learning. However, they are included in this context due to their significant utility in medical writing and manuscript preparation, and their great potentiality of integrating AI soon.

scientific writing during various stages, going from outlining a structure and table of contents, literature reviews, translations, editing, grammar checking, optimizing language and context, data analysis and presentation, formatting and managing citations, generating and formulating abstracts, to ultimately drafting an entire manuscript [8]. AI may also be helpful in increasing the clarity of writing by reducing syntax complexity and by generating tables and graphical forms [9], which could then serve as a means of inspiration for scientists. Hence, AI can ensure greater consistency and precision of a manuscript and provide a faster-streamlined workflow and an enhanced automated publication process [9].

While increased efficiency is likely the highest benefit in manuscript preparation, improving accuracy and quality control are as important to consider when evaluating the benefits of AI. Moreover, AI tools have

shown great potential for non-native English speakers by enabling more accurate translations and improving language clarity [10]. As less than 20% of the world's population speaks English, but close to 75% of scientific writing is produced in English [11], AI can be ethically used to improve English language accessibility and worldwide dissemination.

To evaluate the use of AI in scientific writing, three strategies were recently identified and compared: the traditional human-only, AI-only, and combining AI and human approaches. While none appeared to be superior, each approach offered diverse advantages, disadvantages, and risks for errors that also varied for different healthcare fields and according to prior scientists' experience or skills in AI tools. Interestingly, while AI decreased the writing time, it demonstrated up to 70% citation errors and produced the highest similarity indices, raising a concern about a high likelihood of plagiarism [12].

APPLICATIONS OF AI IN MANUSCRIPT PREPARATION

1. Manuscript outline

An AI-driven outline can help scientists gain a more holistic overview. The request can be formulated based on the paper's main research question or aim and subject. An AI-generated content table may be valuable as it may enhance the comprehensiveness of the topics to be covered, point to related subtopics, and uncover relevant information from other fields that could further foster broader perspectives and ideation in the manuscript.

2. AI for literature search and review and reference management

A literature search to write a research paper's background information or a comprehensive literature review can be achieved with AI assistance. The reference manager, Zotero, which integrates with the web browser, helps to collect research papers. Using inquiry tools such as Elicit facilitates identifying and extracting the requested relevant information from the collected papers. Elicit is designed to conduct literature reviews using semantic queries, allowing easier identification of relevant papers with a mapping system. A chatbot function can further assist in finding answers from the papers, broaden the search queries and output, find new connections, and synthesize new hypotheses to guide new research. Efficiency can also be increased as AI may provide summaries and answer questions based on selected research papers previously uploaded as PDF documents in AI tools such as Elicit. The chatbot then allows a faster reading as the tool can highlight key sentences relevant to the research question. Besides exploring the content of scientific papers, tools such as Scite.ai inform writers on how often a paper has been cited, which can be of guidance when selecting relevant biographies.

Further, the use of reference managers improves and accelerates the generation of the bibliographic list, *e.g.*, by removing duplicates when parallel queries are performed, maintaining consistency in reference formatting and ensuring accuracy, as it may reduce typography and citation errors compared to human manual input.

3. AI for data analysis and representation

Automation of extensive data set analysis and visualization through various graphical representations is largely facilitated by tools such as Python libraries and R packages, which offer statistical analysis. Numerous data management tools based on techniques like heatmaps, scatter plots, advanced algorithms, and predictive modeling techniques have become available for data exploration, analysis, and visualization [7]. The risks linked to human errors are reduced when processing data sets with AI tools, and the research outputs are expedited and accurate.

4. AI for manuscript writing

Manuscript writing can be accelerated with enhanced efficiency and accuracy when assisted or generated with AI. The advantages of AI usage in scientific writing are discussed above in the previous section.

CHALLENGES AND LIMITATIONS OF AI IN SCIENTIFIC WRITING

Despite the numerous and apparent advantages of using AI in scientific writing, several challenges and limitations still cloud the scene. Errors and biases in AI-generated content may arise at several stages, from data collection to the final output. Therefore, specific sensibility and awareness as to the type of data, system-inherent limitations, transparency, and proactive

error detection in AI tools are essential for mitigating AI-related risk of errors [13,14].

1. Undermining researchers' knowledge, skills, and critical thinking

The basis for scientific research is a proper understanding of the published literature. Many hours of reading would be needed to understand the data and conclusions. Over-reliance on AI may diminish the researchers' reading and writing skills, jeopardize their knowledge, and decline their critical thinking abilities. Consequently, AI can risk limiting comprehension of nuanced or highly specialized concepts, result in oversimplifications or misinterpretations of scientific ideas, and compromise the quality of scientific output.

Critical thinking involves a complex process of interpreting and assessing potentially controversial findings [15]. A "barrier of meaning" still exists between AI and human-level intelligence. Humans can perceive and reflect on their thought processes, a cognitive function known as metacognition, which is absent in AI tools. Comprehending a text or a situation involves a perceptual process rooted in mental simulations [16], a capability that AI also lacks. These capabilities have long been recognized as the driving forces behind innovative ideas throughout human history. Since scientific progress depends on creative problem-solving and the development of novel concepts [17], overconfidence in AI may inhibit the cultivation of these essential skills in researchers. Hence, over-reliance on AI poses risks that could stifle humans' imagination, creativity, ingenuity, and innovation.

In the future, combined with AI-assisted tools, the potential decline in individuals' writing skills may result in uniform and standardized publications, ultimately leading to the loss of the personal voice in scientific publications. Therefore, it remains essential to maintain a balance to safeguard researchers' critical thinking and writing abilities, with AI that should be viewed as a complementary tool, not a replacement for human expertise.

2. Risks of inaccuracies, misinformation, and bias amplification

AI tools for text outputs often lack specific mechanisms to evaluate the correctness of their content, and they can be indifferent to highlighting errors. This is because AI models primarily assess the most frequently cited online data or algorithm-based scores for higher probabilities. The functionality of AI depends fundamentally on information created, gathered, documented, and categorized by humans. Suppose AI tools are trained on historical, outdated, non-representative, or misrepresentative data. In that case, their AI-generated outputs carry a risk that should not be underestimated. A study [18] analyzed the performance of ChatGPT for speed and accuracy of the data used to write the paper by Pinna et al [19] and showed that the AI was able to write a "new" scientific paper very quickly. However, this "new" paper also contained "results" from incomplete data from the Pinna et al [19] article.

Therefore, if the inaccurate data are re-ascribed, subsequent authors inadvertently amplify the mistakes. Further, any biases present in the training data can be exacerbated and perpetuated in AI-generated plausible outputs fitting the pattern of their searching questions, sometimes repeatedly and randomly. Such biases and error repetition pose significant challenges, especially in fields such as medicine and health care, and may critically impact patient care outcomes [20,21]. Moreover, when erroneous data are compounded in a meta-analysis, the conclusion may be wrong, with subsequent clinical implications. Even when adequately instructed, AI can amplify an inaccuracy that invalidates the hypothesis. Until today, the strength of AI and LLM output has been the generation of linguistically highest quality writings, but not the accuracy of information.

3. Risk of plagiarism and fabrication

Plagiarism has serious potential when embarking on AI technologies. Relying solely on AI to answer a question without the humans' independent assessment of the literature and AI outcome raises a concern in the academic community about the possibility of plagiarism and claiming the ideas of others as their own without appropriate attribution [22]. Thus, using AI tools to "write" an article bears significant risks of plagiarism and data fabrication. When AI removes the author from the original text, another author—only interrogating previously published data—may unknowingly reach the same conclusions as previous authors, inadvertently committing plagiarism, which may be difficult for reviewers to detect [23]. Importantly, AI may be abused to falsify data or completely fabricate manuscripts, including comprehensive research,

systematic reviews, narrative reviews, video or audio content, or even to manufacture entire articles in publication mills without underlying research [24-26].

AI FOR PLAGIARISM DETECTION, PEER REVIEW AND QUALITY CONTROL

Plagiarism detection tools, such as iThenticate, are often used by scientific journals and publishers to ensure the originality of the manuscript content. Nevertheless, they can detect plagiarism at the sentence level, which renders preventing plagiarism more challenging as AI is also used to generate paraphrases. Additionally, AI detectors such as AI Classifier or Originality find it challenging to classify human-written and AI-written articles [27]. Furthermore, Stadler et al [28] showed that even the most experienced scientists and clinicians could not detect 38% of AI-generated abstracts.

On the other hand, the impact of AI on peer review and quality control in scientific writing is becoming increasingly significant, offering substantial benefits to the peer review process. AI tools, for example, can facilitate a more standardized evaluation process during the submission phase, potentially reducing the human factor in the assessment process [29]. Checco et al [30] discussed the potential of AI to assist human reviewers' decisions when evaluating the quality of a paper. They trained an AI with 3,300 conference proceeding papers, including their peer review evaluations, to infer rules that match the peer review outcome. The study used basic parameters such as word distribution, readability scores, and format. They found correlations with the overall result of the peer review process, suggesting that further developments in machine-learning systems could improve the process's efficiency by reducing the time spent by reviewers and the quality control by flagging low-quality studies.

AI tools continue to evolve to include more sophisticated comparative and anticipatory algorithms, notably by enhancing AI's ability to analyze the content of documents for logical correctness, randomness, bias, and inconsistency [31]. Furthermore, several AI developers, such as SynthID [32] and Google Gemini, are trying technical methods to embed concealed resilient watermarks in AI-generated text. These markers are designed to endure even after removal attempts by a process termed 'scrubbing,' and to retain their ability to signify the document's AI origin, ensuring persistent identification. Nonetheless, despite the sophisticated algorithms in detecting AI-generated content, achieving flawless watermark implementation remains challenging since the algorithm might provide false or inappropriate watermarks when wrongly defining a human document as AI-generated. A recent study used a different approach to detect AI-generating content by not comparing it to similar online content but using typical stylometrics parameters. Surprisingly, this study showed high accuracy in differentiating documents written by humans or ChatGPT-based, reaching 98% and 100% when additionally implementing other classifiers such as XGBoost and Stacking algorithms [33].

ETHICAL, LEGAL, AND REGULATORY CHALLENGES

AI's vast and uncontrolled integration in scientific writing and publication can lead to incrementally serious ethical concerns and introduce complex and insufficiently regulated legal implications that require careful consideration. As previously discussed, several AI challenges are related to authorship, accountability, misconduct, data privacy, data falsification or fabrication, plagiarism, bias, quotation errors, consent, copyright, and transparency, to name a few. The lack of definitive regulations governing AI's role in scientific writing will likely raise further ethical concerns and result in legal conflicts, uncertainties within the academic community, consequences linked to the uptake of misleading information and resulting responsibilities assignments.

Many users of AI-supported documents may not be aware that AI services could inadvertently breach confidentiality or disclose proprietary information, with potential legal consequences. Notably, once information is placed online, it is often irrevocable without a secure removal mechanism.

Furthermore, AI tools do not regulate conflicts of interest or the enforcement of copyright and licensing agreements for publications, nor is the patentability of AI interventions or the intellectual property of AI-generated documents subject to unifying legal standards across nations [34].

1. Authorship and accountability

Accountability is a critical ethical and legal consideration in scientific writing, and thus, one of the primary legal concerns is the issue of "authorship" when AI tools considerably contribute to the development of scientific manuscripts. Significant legal challenges arise regarding the copyright, accountability and liability for errors, research integrity, violations, and fraudulent misconduct introduced by AI-generated content [25,35].

Specifically, the question arises as to whether authorship should be attributed to human researchers, AI tools, affiliated institutions, publishing entities, or even AI developers. AI technologies are tools and should not be listed as authors or co-authors [36]. Human authors are still responsible for carefully reviewing and editing the AI output to avoid incorrect, inconsistent, incomplete, or biased content [37]. Authors may use these technologies to improve readability and language but with human oversight and control of the content.

Currently, there are no clear guidelines, and there is a noticeable absence of legal regulations from national or international authorities on the attribution of authorship in cases involving AI-assisted writing. According to the standard principle in academic writing and in line with the COPE's position statements [38], there is a complete responsibility request about the content by the "human" author, which cannot be allocated in the case of AI-generated content. Meanwhile, several societies, journals, and publishers request the authors to transparently disclose the use of generative AI and AI-technologies, and a statement will appear in the published work [39,40]. Ganjavi recently reported that among the top 100 largest publishers, only 24% provided specific guidance on the use of generative AI, with 15/24 (63%) being among the top 25 publishers [41]. When analyzing specific attitudes in journals, it was reported that of the top 100 ranked journals, mostly belonging to prominent publishers, the majority (87%) had released generative AI guidelines.

2. Call for changes in regulations and ethical code of conduct

The emergence of AI-related ethical and legal challenges underscores the urgent need to update professional and medical ethics and legal frameworks to specifically address the use of AI in scientific research and publication. Implementing clear policies and guidelines will help adherence to ethical and professional standards, mitigate legal risks, and facilitate a smooth transition. Potential regulatory challenges involve imposing restrictions on AI use in sensitive research areas, including the possibility of sanctions, to ensure accountability and maintain the integrity of scientific publications [42]. Notably, regulations on scientific writing are complex because, beyond publishing standards, the freedom of science imposes constitutional limits on government interventions. This ensures that scientific research and expression remain protected from excessive state control.

Nevertheless, to address the current regulatory gap, the European Commission expects an "AI Pact" from hundreds of companies, committing to voluntary self-regulation as early as autumn 2024. Additionally, the European Union (EU) has introduced the AI Act [43], a legally binding detailed AI regulatory framework. The AI Act is set to take full effect on August 2, 2027, although meanwhile, stepwise implementation is planned starting from February 2, 2025. The AI Act introduces a tiered approach to classifying general risks associated with AI use, including health-related risks. These risk classifications range from minimal, such as AI usage in writing clinical notes, to high and even unacceptable risk, particularly in the case of AI diagnostic tools and medical devices [44]. Each classification entails specific obligations for both providers and deployers of AI systems. Notably, these requirements extend beyond the scope of existing regulations, such as the Medical Device Regulations in European countries [45], which have been recently adapted to address AI-specific requirements [46]. Similarly, AI usage in scientific writing requires updating and extending the existing regulating framework.

FUTURE OF AI IN SCIENTIFIC WRITING AND PUBLISHING

History tells us that once a technology has been invented and is readily available, people will use it to their benefit and their detriment. Therefore, we should accept that AI offers valuable opportunities in scientific writing [47]. However, we must also be very wary of possible abuse with negative implications.

AI technology companies are investing huge resources to reduce errors in data generation and improve LLM-generated outputs. It is anticipated that with future progress in AI technology, errors and biases will

be reduced in scientific writing. On the other hand, reviewers and editors must be made aware of advancements and novel AI tools and how to identify AI-written texts to ensure high-quality published papers.

GAF EXPERT STATEMENTS ON AI USE IN SCIENTIFIC WRITING

The GAF Expert Group devised the following AI position statements and recommendations to encourage proper AI usage, address AI limitations, and eliminate the potential for unethical or illegal use of AI technologies.

1. Statements for authors

1. Authors are encouraged to use AI tools to optimize language and reference management in scientific writing.
2. Authors should be equally aware of AI tools' opportunities and limitations to minimize the associated risks.
3. Authors must include a specific disclosure statement, transparently referring to using AI tools and their versions.
4. Authors must describe in the methodology section how and to what extent the AI tools were used in all research stages, including research questions, literature searches, writing processes, reference management, etc.
5. Authors must identify the sections of AI-generated text, when applicable.
6. Authors should carefully check and validate all stages in AI-generated manuscripts.
7. Authors should meticulously read the entire articles searched and critically analyze the retrieved literature and citations to verify their accuracy and ensure that no fabricated or misinterpreted data exists.
8. Authors should rigorously cross-check AI-generated text against reliable sources to exclude errors, inaccuracies, and inconsistencies.
9. Authors should be aware that "humans" are the sole authors of the article and bear full accountability and responsibility for the ethical, legal, copyright, intellectual property, and scientific aspects of the content.
10. Authors should not list AI technologies and tools as authors or co-authors, regardless of how much AI contributed to the text or research.

2. Statements for journals' editors and publishers

11. Journal editors and publishers should use AI technologies to examine and evaluate the manuscripts for AI inputs and any potential violations or misconduct.
12. Journals and publishers should clearly disclose the AI technologies used on their web pages.
13. Journals and publishers are encouraged to implement recogniton or certification systems for manuscripts that adhere to best practices in AI usage, thereby promoting transparency and responsible adoption of AI technologies.

3. Statements for developers

14. Developers of AI technologies should create identifiable markers for AI-generated text, such as permanent, non-removable watermarks..
15. Developers of AI technologies and worldwide regulatory and legal bodies are urged to create and continually update user manuals, best practices, and ethical guidelines for AI usage to help researchers understand the appropriate contexts and boundaries for using AI in academic writing and research.

CONCLUSIONS

AI has revolutionized medical research and scientific writing by facilitating comprehensive literature reviews, data analysis, content drafting, grammar refinement, plagiarism detection, and translation. It enhances clarity, reduces human error, and provides standardized tools to streamline peer-review processes while allowing non-English-speaking authors to publish in leading journals and increasing global accessibility of research. However, the use of AI in scientific writing raises significant concerns. AI-generated content may be based on incomplete or inaccurate information, leading to factual errors, misinformation, plagiarism, and data falsification or fabrication. Biases inherent in AI training data may skew interpretations. Over-reliance on AI can diminish critical thinking, creativity, and writing skills among researchers. Additionally, there are legal and ethical challenges, including copyright issues, confidentiality risks, and insufficient regula-

tion of authorship in AI-assisted works. Therefore, it is important to recognize the potential risks associated with AI use, to take appropriate precautions to mitigate these risks by maintaining human judgment and critical thinking, and to use it as a complementary tool rather than a replacement for human effort in the writing process. The GAF position statements and expert recommendations provide guidelines for ensuring responsible AI integration in scientific writing and leveraging AI efficiency while mitigating its potential risks and limitations.

TAKE-HOME MESSAGE

AI has revolutionized scientific writing by enhancing efficiency, precision, and accessibility, but it also presents risks such as inaccuracies, biases, and ethical concerns. The GAF position statements emphasize transparency, ethical practices, and human oversight to ensure that AI complements rather than replaces human expertise. Responsible integration of AI can elevate the quality and integrity of scientific publications globally.

Conflict of Interest

The authors have nothing to disclose.

Funding

None.

Acknowledgements

None.

Author Contribution

Conceptualization: AA. Methodology: AA. Data curation: HA. Writing – original draft: All authors. Supervision: TAAH, AA. Validation: All authors. Writing – review & editing: All authors.

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