



# Exploring the Potential of GPT-4 in Biomedical Engineering: The Dawn of a New Era

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Received: 23 April 2023 / Accepted: 24 April 2023 / Published online: 28 April 2023  
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## Abstract

Biomedical engineering is a relatively young interdisciplinary field based on engineering, biology, and medicine. Of note, the rapid progress of artificial intelligence (AI)-based technologies has made a significant impact on the biomedical engineering field, and continuously bring innovations and breakthroughs. Recently, ChatGPT, an AI chatbot developed by OpenAI company, has gained tremendous attention due to its powerful natural language generation and understanding ability. In this study, we explored potential of GPT-4 in the eight branches of biomedical engineering including medical imaging, medical devices, bioinformatics, biomaterials, biomechanics, gene and cell engineering, tissue engineering, and neural engineering. Our results show that the application of GPT-4 will bring new opportunities for the development of this field.

**Keywords** GPT-4 · Artificial intelligence · Chatbot · Biomedical engineering · New era

## Background

Biomedical engineering is a relatively young interdisciplinary field based on engineering, biology, and medicine. The researches done in this domain are very diverse and extensive. According to the journal of *Annals of Biomedical Engineering*, one of the main aims of biomedical engineering is to offer integrated approaches to solve biological and biomedical problems. In recent years, new technology in biomedical engineering, especially

genomics and proteomics, robot-assisted surgery, virtual reality and augmented reality, etc. has attracted much attention. Meanwhile, the rapid progress of artificial intelligence (AI)-based technologies such as AI-assisted diagnosis has made a significant impact on the biomedical engineering field, and continuously bring innovations and breakthroughs. Of note, with the developments of AI, the powerful AI-related technologies have emerged in the natural language-processing (NLP) field. Recently, ChatGPT, an AI chatbot developed by OpenAI company, has gained tremendous attention due to its powerful natural language generation and understanding ability [1–3]. GPT-4 is the latest version of the GPT series, which has shown excellent performance on many NLP tasks. Multiple studies have identified a few potential applications

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Associate Editor Stefan M. Duma oversaw the review of this article.

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of GPT-4 in the field of clinical medicine, such as transformation of free-text radiology reports into structured reporting, an AI-powered virtual assistant for spinal surgeons or surgeons specialized in joint arthroplasty, as well as personalized virtual assistant for bariatric surgery patients [4–7]. In addition, one study by Lee et al. has provided detailed summary on the benefits, limits, and risks of GPT-4 for medicine [8]. However, to the best of our knowledge, no study has discussed the potential applications of GPT-4 in biomedical engineering filed.

In view of this, using an online survey (<https://chat.openai.com/?model=gpt-4>), we conducted an exploratory study to figure out its application prospects in biomedical engineering. In addition, taking the broad scope of the field, we will limit our questions to the following branches of biomedical engineering such as medical imaging, medical devices, bioinformatics, biomaterials, biomechanics, gene and cell engineering, tissue engineering, and neural engineering (Fig. 1).

## The Potential Applications of GPT-4 in Medical Imaging

Answer from GPT-4: GPT-4, as a highly advanced AI language model, has the potential to be applied to various aspects of medical imaging, enhancing the development of new techniques, improving accuracy, and facilitating more efficient interpretation of the images. There are some potential applications of GPT-4 in medical imaging:

### 1. Image Analysis and Interpretation

GPT-4 can be trained to analyze and interpret medical images, such as X-rays, MRIs, and ultrasounds, by using its natural language-processing capabilities to understand the features and structures within the images. This could help in the identification of anomalies, diseases, or injuries more accurately and quickly, reducing the burden on radiologists and other medical professionals.

### 2. Enhanced Image Reconstruction

GPT-4 could be used to develop more advanced algorithms for reconstructing high-quality images from raw data obtained through medical imaging techniques. This could lead to improved image quality and resolution, allowing for better visualization and understanding of the internal structures and functions of living organisms.

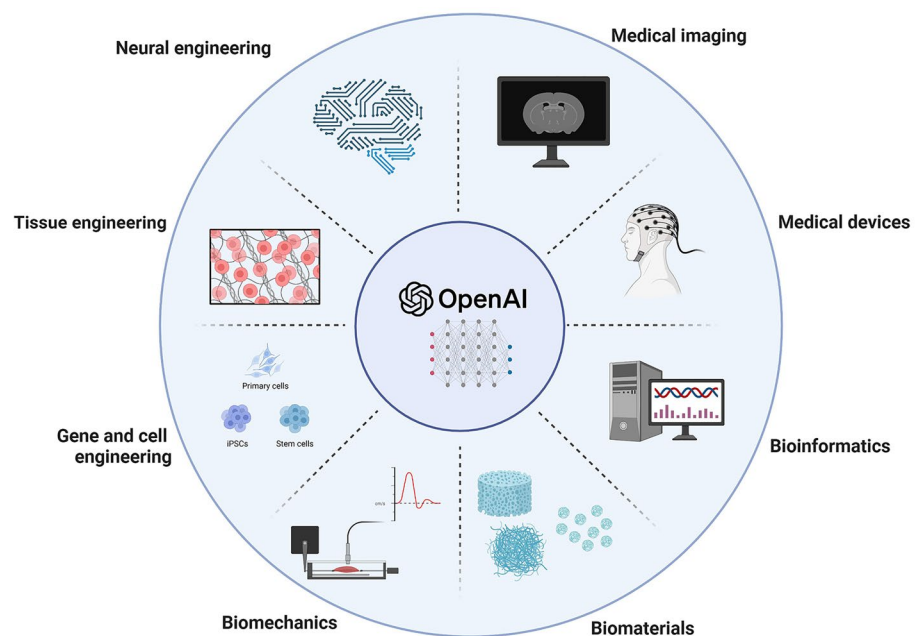
### 3. Anomaly Detection and Segmentation

By leveraging the pattern recognition capabilities of GPT-4, it could be used to identify and segment anomalies within medical images, such as tumors or lesions, more accurately. This could aid in early diagnosis and treatment planning for various medical conditions.

### 4. Multi-modal Data Fusion

GPT-4 could be employed to combine information from different medical imaging modalities, such as X-ray, MRI, and

**Fig. 1** The potential applications of GPT-4 in biomedical engineering (Created by BioRender)



ultrasound, to create a more comprehensive and informative view of a patient's condition. This could improve diagnostic accuracy and contribute to more personalized treatment plans.

## 5. Assisting in Medical Education

GPT-4 could be used to create educational materials for medical students, such as simulated medical images with detailed descriptions and explanations of various conditions, helping them to develop a deeper understanding of anatomy, physiology, and pathology.

## 6. Enhanced Computer-Aided Diagnosis (CAD) Systems

Integrating GPT-4 into CAD systems could improve their accuracy and efficiency, enabling them to better support medical professionals in their decision-making processes. This could lead to more accurate diagnoses and more effective treatment plans.

## 7. Patient Communication and Report Generation

GPT-4 could be used to generate clear and concise reports of medical imaging findings, tailored to the patient's level of understanding, which could help improve patient communication and overall satisfaction with their care.

## 8. Predictive Modeling

GPT-4's advanced machine-learning capabilities could be applied to develop predictive models based on medical imaging data, which could help to identify patients at risk of developing certain conditions or to predict the progression of diseases.

## The Potential Applications of GPT-4 in Medical Devices

Answer from GPT-4: GPT-4 has the potential to revolutionize the medical device industry by assisting in various aspects of designing, developing, and optimizing medical devices. The advanced natural language-processing and deep-learning capabilities of GPT-4 can be harnessed to enhance the overall process of medical device creation, from ideation to implementation. Here are some potential applications of GPT-4 in the medical device industry:

### 1. Design and Ideation

GPT-4 can analyze large volumes of medical literature and patents to identify emerging trends, technologies, and potential opportunities for new medical devices. This can help medical device manufacturers generate novel ideas and designs.

### 2. Enhanced Prototyping

GPT-4 can contribute to the design process by suggesting optimal materials, geometries, and fabrication techniques based on the device's requirements and constraints. This can lead to more effective and efficient prototypes.

### 3. Simulation and Analysis

GPT-4 can assist in running complex simulations to assess the performance, safety, and reliability of medical devices. By processing large datasets, GPT-4 can provide insights into potential failure modes, performance bottlenecks, and opportunities for optimization.

### 4. Clinical Trial Design

GPT-4 can help design clinical trials by identifying appropriate patient populations, determining optimal sample sizes, and suggesting relevant outcome measures. This can lead to more efficient and targeted clinical trials, ultimately speeding up the regulatory approval process.

### 5. Personalized Medicine

GPT-4 can be integrated into medical devices to provide personalized diagnosis, treatment, and prevention plans based on a patient's genetic makeup, medical history, and other relevant data. This can lead to more effective and individualized care.

### 6. Training and Education

GPT-4 can be used to develop virtual reality and augmented reality simulations for training medical professionals in the use of new medical devices. This can help reduce learning curves and increase adoption rates of innovative technologies.

### 7. Post-market Surveillance

GPT-4 can analyze post-market data, such as adverse event reports and customer feedback, to identify potential safety issues and areas for improvement. This can lead to

continuous improvement of medical devices and enhanced patient safety.

## 8. Regulatory Compliance

GPT-4 can assist medical device manufacturers in navigating complex regulatory landscapes by providing guidance on relevant standards, documentation requirements, and submission processes.

## 9. Technical Documentation

GPT-4 can automate the creation of technical documentation, such as user manuals and maintenance guides, thereby reducing the time and resources required for these tasks.

## 10. Customer Support

GPT-4 can be integrated into customer support systems to provide instant and accurate responses to user queries, reducing the burden on support staff and improving overall customer satisfaction.

# The Potential Applications of GPT-4 in Bioinformatics

Answer from GPT-4: GPT-4 has tremendous potential in the field of bioinformatics, as it is capable of processing and understanding large volumes of complex data. By leveraging its natural language-processing and machine-learning capabilities, GPT-4 can be applied to a wide range of bioinformatics tasks, including genomics, proteomics, and other related areas. Some potential applications include

## 1. Gene Function Prediction

GPT-4 can be used to predict the function of unknown genes based on their sequence and structural features. By analyzing patterns and relationships within large-scale genomic data, the model can identify putative functions for genes with previously unknown roles.

## 2. Protein Structure Prediction

GPT-4 can be employed to predict the three-dimensional structure of proteins from their amino acid sequences. By recognizing patterns and correlations in protein sequence data, the model can provide insights into the folding patterns and functional properties of proteins.

## 3. Drug Discovery

GPT-4 can help streamline the drug discovery process by analyzing existing drug-target interactions and predicting potential new drug candidates. The model can also be used to design novel molecules with specific properties or to optimize existing drug candidates.

## 4. Personalized Medicine

By analyzing genomic data, GPT-4 can aid in the development of personalized treatment plans for patients, based on their individual genetic makeup. This can improve treatment efficacy and minimize adverse side effects.

## 5. Comparative Genomics

GPT-4 can be used to perform comparative genomic analyses, which involve comparing the genomes of different organisms to identify similarities and differences. This can provide insights into evolutionary relationships, gene function, and species-specific adaptations.

## 6. Epigenetics

GPT-4 can help researchers study the complex interactions between genetics and environmental factors that influence gene expression. By analyzing large-scale epigenetic data, the model can help identify patterns and associations that contribute to various diseases and conditions.

## 7. Metagenomics

GPT-4 can be used to analyze metagenomic data, which involves the study of genetic material from environmental samples. This can help researchers understand the composition and function of microbial communities in various ecosystems, as well as their roles in processes such as nutrient cycling and disease transmission.

## 8. Network Biology

GPT-4 can be employed to analyze complex biological networks, such as protein–protein interaction networks or gene regulatory networks. By identifying key players and their interactions, the model can help researchers understand the underlying mechanisms of various biological processes and diseases.

## 9. Text Mining and Knowledge Extraction

GPT-4 can be used to mine scientific literature, extracting relevant information, and identifying hidden patterns and

relationships within the text. This can help researchers stay up-to-date with the latest discoveries and contribute to the advancement of knowledge in the field of bioinformatics.

## 10. Education and Training

GPT-4 can be used to create interactive educational tools and resources, aiding in the teaching and learning of complex bioinformatics concepts. Its natural language-processing capabilities can also help in developing more efficient query systems for biological databases.

## The Potential Applications of GPT-4 in Biomaterials

Answer from GPT-4: GPT-4, as a powerful language model, has various potential applications in the field of biomaterials. Biomaterials are synthetic or natural materials used in medical applications, such as implants or replacements for human tissue. GPT-4 can assist in the research and development of biomaterials with good compatibility with organisms in several ways:

### 1. Literature Review and Analysis

GPT-4 can help researchers quickly analyze vast amounts of literature, summarizing findings, and identifying trends in biomaterials research. It can also aid in finding correlations between different materials and their biocompatibility, mechanical properties, and overall performance.

### 2. Hypothesis Generation

GPT-4 can generate new hypotheses based on existing data and knowledge, proposing novel materials or strategies for improved biocompatibility and tissue integration. This can potentially lead to groundbreaking discoveries in the field of biomaterials.

### 3. Simulation and Modeling

GPT-4 can be used to simulate and model complex biological systems and the interactions between biomaterials and human tissues. This can help researchers better understand the behavior of these materials in the body and optimize their properties for specific applications.

### 4. Design of Experiments

GPT-4 can help researchers design better experiments by identifying critical variables and suggesting optimal experimental conditions. This can improve the efficiency of

research and reduce the time required for new biomaterials to move from the lab to the clinic.

## 5. Data Analysis and Interpretation

GPT-4 can assist in the analysis and interpretation of experimental results, identifying patterns and trends that may not be apparent to human researchers. This can lead to new insights and a deeper understanding of biomaterials and their applications.

## 6. Collaboration and Communication

GPT-4 can facilitate collaboration between researchers from different disciplines and backgrounds by providing a common language and platform for sharing knowledge and ideas. This can accelerate the pace of biomaterials research and development.

## 7. Personalized Medicine

GPT-4 can be used to analyze individual patient data and suggest personalized biomaterial solutions based on a patient's unique needs, preferences, and medical history. This can improve patient outcomes and overall quality of life.

## 8. Education and Training

GPT-4 can be used as a teaching tool for students and professionals in the field of biomaterials, providing interactive learning experiences and up-to-date information on the latest research and advancements.

## The Potential Applications of GPT-4 in Biomechanics

Answer from GPT-4: GPT-4 can have several potential applications in the field of biomechanics, particularly in understanding the mechanical behavior of organisms and analyzing the properties of biological tissues, organs, and systems. Some of these applications include

### 1. Data Analysis and Interpretation

GPT-4 can be used to analyze large datasets generated from biomechanical experiments, simulations, or medical imaging. It can identify patterns, trends, and correlations in the data, assisting researchers in uncovering novel insights into biomechanics.

## 2. Computational Modeling

GPT-4 can be used to develop and refine computational models of biological tissues, organs, and systems. By leveraging natural language-processing and machine-learning techniques, the model can be trained to predict mechanical properties or simulate the mechanical behavior of various biological structures under various conditions, including the effects of external forces, injury, or disease.

## 3. Personalized Medicine

GPT-4 can help develop personalized biomechanical models that account for individual differences in anatomy, physiology, and biomechanics. Such models can inform the design of customized medical devices, orthotics, and prosthetics, or guide personalized rehabilitation programs.

## 4. Medical Imaging Analysis

GPT-4 can be employed to analyze medical images such as MRI, CT, and ultrasound scans, extracting relevant biomechanical information and aiding in the diagnosis and monitoring of various conditions related to biomechanics, such as osteoarthritis, osteoporosis, or sports injuries.

## 5. Surgical Planning and Simulation

GPT-4 can be utilized to optimize surgical planning by simulating the mechanical effects of various surgical procedures on the body. This can help surgeons make informed decisions, minimize surgical risks, and improve patient outcomes.

## 6. Design of Bioinspired Materials and Structures

GPT-4 can analyze and learn from the unique mechanical properties of biological tissues and systems, inspiring the design of innovative materials and structures that mimic their properties for various applications, such as aerospace, automotive, and civil engineering.

## 7. Robotics and Exoskeletons

GPT-4 can help design robots and exoskeletons that mimic the biomechanical properties and movement patterns of humans or animals, allowing them to move more efficiently and naturally in their environment.

## 8. Education and Training

GPT-4 can be employed to develop interactive and immersive educational tools for teaching biomechanics to students,

medical professionals, and researchers. This can facilitate a deeper understanding of the subject and promote effective learning.

## 9. Collaborative Research

GPT-4 can help facilitate interdisciplinary research by assisting in the translation and integration of knowledge from various fields, such as biology, physics, engineering, and computer science, to advance our understanding of biomechanics.

## The Potential Applications of GPT-4 in Gene and Cell Engineering

Answer from GPT-4: GPT-4, as a powerful AI language model, has great potential in various fields, including gene and cell engineering. Its ability to process vast amounts of data, identify patterns, and generate meaningful insights makes it an ideal tool for researchers working in these areas. Here are some potential applications of GPT-4 in gene and cell engineering:

### 1. Literature Review and Hypothesis Generation

GPT-4 can help researchers in gene and cell engineering by analyzing vast amounts of scientific literature and generating hypotheses. By identifying connections and patterns in previous research, GPT-4 can help researchers to develop novel ideas for experiments and guide their study designs.

### 2. Predictive Modeling

GPT-4 can be used to create predictive models for various aspects of gene and cell engineering, such as gene expression, protein folding, and the efficiency of CRISPR-based gene editing. These models can help researchers to optimize experimental conditions, predict the outcome of genetic modifications, and identify potential off-target effects.

### 3. Design of Gene Editing Tools

GPT-4 can be used to optimize the design of gene-editing tools, such as CRISPR guide RNAs, to maximize target specificity and minimize off-target effects. This can improve the safety and efficacy of gene-editing technologies, leading to more successful applications in gene therapy and cell therapy.

#### 4. Identification of Novel Therapeutic Targets

By analyzing large datasets, GPT-4 can identify potential therapeutic targets for various diseases, based on the genes and pathways involved. This can help researchers to prioritize their efforts in developing gene and cell therapies and guide their experimental designs.

#### 5. Personalized Medicine

GPT-4 can be used to analyze individual patients' genomic data to identify unique genetic variants, predict the potential impact of these variants on gene function, and guide the development of personalized gene and cell therapies.

#### 6. Optimization of Cell Therapies

GPT-4 can help optimize cell engineering strategies by analyzing data on cell differentiation, proliferation, and function. This can enable the development of more effective cell therapies for diseases like cancer, diabetes, and neurodegenerative disorders.

#### 7. Drug Discovery

GPT-4 can be used to identify potential drug candidates for gene and cell therapies by analyzing the interactions between molecules, proteins, and genes. It can also be used to predict the pharmacokinetics and pharmacodynamics of these drug candidates, helping researchers select the most promising compounds for further development.

#### 8. Bioinformatics and Data Analysis

GPT-4 can assist in the analysis of large and complex datasets generated in gene and cell engineering research, including genomic, transcriptomic, proteomic, and epigenetic data. By identifying patterns and relationships within these datasets, GPT-4 can help researchers to uncover novel insights and generate new hypotheses.

### The Potential Applications of GPT-4 in Tissue Engineering

Answer from GPT-4: GPT-4, as a powerful AI language model, can significantly contribute to the field of tissue engineering through various applications. Although GPT-4 itself does not directly interact with cells, biomaterials, or growth factors, its ability to analyze data, make

predictions, and generate insights can be harnessed in several ways to support tissue-engineering research:

#### 1. Data Analysis and Pattern Recognition

GPT-4 can help researchers to analyze large volumes of data generated during tissue-engineering experiments. It can identify patterns and correlations in the data, assisting in the discovery of new insights into the interactions between cells, biomaterials, and growth factors. This could lead to the development of more effective tissue-engineering strategies.

#### 2. Literature Review and Knowledge Synthesis

GPT-4 can be used to quickly review and synthesize knowledge from the vast amount of scientific literature available in tissue engineering. By keeping up-to-date with the latest findings, researchers can better inform their work and avoid duplicating efforts.

#### 3. Predictive Modeling

GPT-4 can be employed to develop predictive models of cellular behavior, biomaterial properties, and growth factor interactions based on the available data. These models can help researchers to simulate and test various scenarios, leading to more efficient experimental designs and a better understanding of the complex dynamics involved in tissue engineering.

#### 4. Biomaterials and Scaffold Design

GPT-4 can assist in the design of novel biomaterials and scaffolds for tissue-engineering applications. By analyzing the properties and performance of existing materials, GPT-4 can suggest potential improvements or entirely new materials that may be more suitable for specific tissue-engineering applications.

#### 5. Personalized Medicine

GPT-4 can be used to support the development of personalized tissue-engineering therapies. By analyzing individual patient data, GPT-4 can help identify the most appropriate combination of cells, biomaterials, and growth factors for a particular patient's needs, leading to more effective and targeted treatments.

#### 6. Drug Discovery and Development

GPT-4 can facilitate the discovery and development of new drugs and growth factors for tissue-engineering applications. By analyzing the molecular structure and properties of

known drugs and growth factors, GPT-4 can suggest potential modifications or new compounds that could be more effective in promoting tissue growth and repair.

## 7. Education and Training

GPT-4 can be utilized as an educational tool to help teach and train the next generation of tissue engineers. Its ability to generate accurate, up-to-date information on demand can be invaluable for students and professionals looking to learn more about the field.

## The Potential Applications of GPT-4 in Neural Engineering

Answer from GPT-4: GPT-4, as a state-of-the-art language model, holds significant potential for various applications in the field of neural engineering. While the primary focus of GPT-4 is natural language processing, it can be applied to various aspects of neural engineering, including the design, development, and implementation of techniques and devices for nervous system research, diagnosis, and treatment. Some potential applications include

### 1. Data Analysis and Interpretation

GPT-4's powerful pattern recognition and predictive capabilities can be harnessed to analyze large datasets from neurological experiments, such as EEG, fMRI, and single-cell recordings. This can help researchers identify patterns, trends, and correlations that may not be easily discernible with traditional methods, leading to new insights and discoveries in the field.

### 2. Assisting in the Development of Neuroprosthetic Devices

GPT-4 can be used to process and analyze neural signals recorded from the brain, spinal cord, or peripheral nerves. This information can then be used to design and optimize neuroprosthetic devices, such as brain–computer interfaces (BCIs) and neural-controlled prosthetic limbs, improving their performance and enabling better communication between the device and the user's nervous system.

### 3. Personalized Diagnosis and Treatment

GPT-4 can be used to analyze individual patient data to generate personalized diagnostic and treatment plans. By integrating information from various sources, including genetic data, medical history, and neural imaging, GPT-4 can assist clinicians in making more accurate diagnoses and selecting

the most appropriate treatment options for patients with neurological disorders.

## 4. Drug Discovery and Development

GPT-4 can be utilized to predict the efficacy and safety of new compounds for the treatment of neurological disorders. By analyzing existing data on drug–target interactions, GPT-4 can identify potential drug candidates, optimize their chemical structures, and predict possible side effects, thereby expediting the drug discovery and development process.

## 5. Neural Simulation and Modeling

GPT-4 can be applied to develop more accurate and detailed computational models of neural systems, which can be used to better understand the underlying mechanisms of nervous system function and dysfunction. These models can also be used for testing hypotheses, validating experimental results, and guiding future research.

## 6. Virtual Assistance for Patients and Caregivers

GPT-4 can be employed as a virtual assistant to provide support and guidance to patients with neurological disorders and their caregivers. By answering questions, providing information, and suggesting coping strategies, GPT-4 can help improve the quality of life for individuals living with these conditions.

## 7. Enhancing Neurorehabilitation

GPT-4 can be used to develop personalized neurorehabilitation programs for patients recovering from neurological injuries or disorders. By analyzing patient-specific data, GPT-4 can generate tailored rehabilitation plans that optimize the speed and extent of recovery.

## 8. Educational and Training Tools

GPT-4 can be used to develop interactive educational and training tools for students and professionals in the field of neural engineering. By providing personalized feedback, generating realistic case studies, and simulating complex scenarios, GPT-4 can enhance learning outcomes and better prepare individuals for real-world challenges in the field.

## Conclusion

Biomedical engineering is a relatively young discipline that has rapidly evolved to become a full-fledged specialty. Research and development in this area play an important role



in improving healthcare and improving human health. In this study, we explored potential of GPT-4 in the eight branches of biomedical engineering. From the answers from GPT-4, it is not hard to draw a conclusion that GPT-4 has a promising application potential and may bring revolutionary changes in the field of biomedical engineering. In terms of the fields in biomedical engineering such as medical imaging, medical devices, bioinformatics, biomaterials, biomechanics, gene and cell engineering, tissue engineering, and neural engineering, GPT-4 could be the right-hand man for scientists to develop new technologies more efficiently, optimize medical device design, improve diagnostic accuracy, and eventually achieve the purpose of maximizing the clinical efficacy of patients.

In addition, as also can be seen from these answers, GPT-4 always gives feedbacks from different aspects. After summarizing these answers, a total of 84 potential application directions was given by this program. Among them, the roles of training and education and personalized medicine both have occurred for seven times. This finding suggests that GPT-4 can be an important vehicle for medical training and education, as well as patients' personalized treatment. In previous studies, Nakhleh et al., [9] found that in addition to accurately answer all questions from diabetes knowledge questionnaire, ChatGPT was also able to provide decent explanations. They believed that AI-based ChatGPT could serve as an important tool to create personalized and automated diabetes patient education materials. Some scholars are also optimistic that GPT-4 performed more excellent than GPT-3.5 on the United States Medical Licensing Exams (USMLE), indicating its proficiency in biomedical knowledge and potential role for enhancing learning in medical education [10]. Meanwhile, one study published by Nature also talk about how to use ChatGPT responsibly in university teaching [11].

However, despite the great potential of GPT-4 in biomedical engineering, several challenges still need to be overcome during practical applications. For example, the use of ChatGPT or GPT-4 could cause data privacy and cybersecurity concerns. In addition, compared with conventional search engines, GPT-4 also has the shortcomings such as the lack of reliability and transparency [12, 13]. Therefore, whether in biomedical engineering or other fields, the application of GPT-4 still needs a lot of empirical research to verify its effectiveness and reliability in actual scenarios. Despite this, with the advances of AI in natural language processing, we are at the dawn of a new and exciting era in biomedical engineering. We have reasons to believe the application of GPT-4 will bring new opportunities for the development of this field.

**Acknowledgements** We thank Prof. Zaijie Sun from Xiangyang Central Hospital for his linguistic assistance during the preparation of this manuscript. The author acknowledges that this article was partially generated

by ChatGPT (powered by OpenAI's language model, GPT-4; <http://openai.com>). The editing was performed by the author.

**Author Contributions** KC: Conceptualization, methodology, data curation, formal analysis, resources, investigation, writing—original draft, writing—review and editing; QG: Conceptualization, formal analysis, resources, investigation; YH: Conceptualization, formal analysis, resources, investigation; YL: Methodology, data curation, formal analysis, resources; SG: Conceptualization, methodology, data curation, formal analysis, resources, investigation; HW: Conceptualization, methodology, data curation, formal analysis, resources, and investigation.

**Data Availability** Not applicable.

## Declarations

**Conflict of interest** The authors declare no conflict of interest.

**Ethical Approval** This study does not include any individual-level data and thus does not require any ethical approval.

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