Applications of Artificial Intelligence and Personalized Medicine in Surgery

Erfanian R. MD[1], Yaghoubi Asl O. MD[2*]

Abstract:

The integration of artificial intelligence (AI) into medicine, particularly personalized medicine, has made significant progress. AI is revolutionizing healthcare by enabling the analysis of medical images, genetic data, and electronic health records to provide more accurate and timely diagnoses. By identifying individual patient characteristics and predicting treatment outcomes, AI aids in developing personalized treatment plans. Additionally, AI is employed in robotic surgery, image-guided interventions, and other surgical procedures.

AI is increasingly integrated into surgical planning to enhance precision and improve outcomes. Despite its significant potential in medicine, challenges such as data privacy concerns and the need for robust validation remain. This review explores the most important findings regarding the applications of AI and personalized medicine in surgery.

Keywords:* *Artificial Intelligence, Robotic Surgical Procedures, Precision Medicine

Introduction

Artificial intelligence (AI) in medicine has a history spanning over 50 years. Early applications included rule-based expert systems such as MYCIN, which provided antibiotic recommendations. MYCIN was designed based on the suffixes of antifungal names and aimed to identify the causative agents of diseases by assessing their severity and recommending appropriate antibiotics. Initially, AI in medicine focused on general problem-solving, but evolved between 1975 and 1982 into systems addressing specific scientific challenges. Despite early limitations due to insufficient computational power, AI in medicine has made remarkable progress. Recent advancements include machine learning and deep learning techniques for tasks such as detecting cancer cells in histology images. AI applications now encompass disease diagnosis, drug development, personalized medicine, and robotic surgery. Several AI tools have received approval from the U.S. Food and Drug Administration (FDA). However, challenges related to usability, transparency, safety, and the need for additional clinical trials persist. This field continues to evolve, with increasing interactions between academic research and industry.

Personalized medicine is an emerging approach that tailors medical treatment based on the unique genetic, genomic, and environmental information of each patient.

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Its goal is to optimize disease prevention strategies and improve treatment efficacy through a molecular understanding of diseases. Personalized medicine has the potential to transform healthcare by enabling more precise diagnoses, safer drug prescriptions, and more effective treatments. This approach relies on biomarkers and genetic profiles to guide decision-making in disease diagnosis, prevention, and treatment. The benefits of personalized medicine include reduced trial-and-error prescribing, fewer drug side effects, and improved patient adherence to treatment. However, challenges remain in integrating personalized medicine into public health practices, developing standardized guidelines, and ensuring access to cost-effective diagnostic tests in both developed and developing countries.

AI is transforming personalized medicine by enabling the analysis of complex biomedical data and tailoring treatments to individual patients. AI algorithms, including artificial neural networks, support vector machines, and fuzzy logic, have shown promising results in disease diagnosis and treatment optimization. Successfully integrating AI into personalized medicine requires acceptable performance, interpretability, and validation across large cohorts. AI facilitates the analysis of multimodal data, including genomics, proteomics, and health records, to predict disease risk and enhance diagnostic accuracy. However, challenges such as data privacy, bias, and regulatory concerns must be addressed. Advances in AI for personalized medicine depend on data standardization and collection, multimodal approaches, collaboration with disease specialists, and clinical validation of AI findings.

The aim of this article is to provide surgeons with a comprehensive overview of the applications of AI and personalized medicine.

Methodology

This review utilized the AI tool Elicit to identify relevant articles using practical keywords, and the content was organized categorically.

Results

Robotic Surgery

Robotic surgery has evolved significantly over recent decades, transforming surgical procedures and patient care. The concept of robots dates back thousands of years, with early examples found in Greek mythology and Leonardo da Vinci's inventions. Modern robotic surgery emerged approximately 35 years ago and has expanded rapidly due to technological advancements over the past two decades. The da Vinci Surgical System, approved by the FDA in 2000, has become the dominant robotic platform worldwide, with over 3,000 systems installed and more than 200,000 surgeries performed annually. Robotic surgery offers minimally invasive procedures, enhanced visualization, superior dexterity, and precision. Despite potential complications, this technology has proven to be safe and effective, particularly in urology for procedures such as prostatectomy, cystectomy, and nephrectomy.

AI is revolutionizing robotic surgery by improving preoperative planning through the analysis of imaging data to provide precise anatomical information. During surgery, AI improves precision by using augmented reality, force measurement, and margin detection. It also enables the automation of certain surgical steps and supports real-time decision-making. Furthermore, AI significantly contributes to surgical training by providing automated skill assessments and specialized feedback for trainees. The integration of AI with robotic systems promises the development of semi-autonomous surgical robots, potentially leading to surgeries with minimal human intervention. However, ethical considerations and the need for further research are emphasized before fully implementing AI in robotic surgery.

Neurosurgery

Personalized medicine in neurosurgery, particularly for brain tumors and cerebrovascular disorders, is advancing rapidly. It uses genomic, proteomic, and epigenetic biomarkers to tailor treatments to individual patients. In neuro-oncology, personalized approaches have progressed

toward targeted therapies based on tumor molecular profiles. Advanced imaging techniques enable safer tumor resections by accurately identifying critical brain regions. For cerebral aneurysms, personalized medicine improves risk assessment and treatment selection for unruptured aneurysms and aids in managing secondary complications in patients with subarachnoid hemorrhage. The integration of quantitative neuroimaging and molecular-based approaches, known as radiogenomics, shows promise in characterizing patient aneurysms. As personalized medicine continues to evolve, it is expected to improve patient outcomes and reduce healthcare costs in neurosurgery.

AI is revolutionizing neurosurgery by enhancing patient outcomes, reducing complications, and improving surgical efficiency. Applications of AI in neurosurgery include preoperative planning, intraoperative guidance, continuous monitoring, and postoperative care. These technologies assist with image segmentation, surgical planning, and event prediction, thereby complementing neurosurgeons' skills and decision-making processes. The potential of AI extends to personalized medicine, virtual reality, and robotic surgery, promising a transformative impact on neurosurgical practice. Additionally, AI facilitates data collection, processing, and storage in both clinical and experimental settings. While AI offers numerous benefits, challenges such as data quality, privacy concerns, and regulatory frameworks must be addressed. Overall, the integration of AI in neurosurgery aims to improve patient care, reduce costs, and expand access to high-quality healthcare.

Orthopedic Surgery

Personalized medicine in orthopedic surgery holds significant potential for improving patient care. In spinal surgery, advancements in surgical planning software and 3D printing technologies have improved the accuracy of postoperative alignment predictions and pedicle screw placement. Personalized preoperative risk assessments may improve the accuracy of information provided to patients, thereby strengthening the informed consent processes. Additionally, 3D printing has multiple applications in orthopedics, including advanced preoperative planning, patient-specific surgical instruments, customized orthotic treatments, and personalized implants or prosthetics. These personalized approaches have demonstrated the ability to improve care throughout all stages of surgical management, from preoperative planning to postoperative outcomes. However, further rigorous studies are necessary to fully evaluate the impact of personalized preoperative risk communication.

AI is rapidly transforming orthopedic surgery, offering significant improvements in diagnosis, treatment planning, and patient outcomes. Applications of AI include automated image analysis for detecting fractures and tumors, predictive models for clinical outcomes, and continuous rehabilitation monitoring. These technologies enhance personalized medicine by optimizing patient selection, surgical planning, and safety. Additionally, AI promises improved resource utilization and reduced healthcare costs. Computer vision has been extensively studied in orthopedics, with applications such as fracture classification and prosthetic implant monitoring. Despite its potential, challenges remain in ensuring external validation, addressing ethical concerns, and maintaining data quality. Ethical considerations are paramount in the development and implementation of these technologies.

Pediatric Surgery

Personalized medicine in pediatric surgery is an emerging field that leverages genomic research and stem cell studies to improve patient care. Recent advances in biomedical and computational sciences have facilitated the analysis of large-scale data, leading to the development of strategies for prevention, diagnosis, and early intervention. Genetic research is progressing rapidly, with promising applications in postoperative pain management, including predicting pain sensitivity and analgesic metabolism. In pediatric cardiology, genomic discoveries are guiding the development of new

diagnostic tools, disease risk prediction models, and the optimization of responses to medications and surgical interventions. Next-generation sequencing is used for clinical genetic testing and non-invasive prenatal testing, offering safer and more accurate diagnostic options. By identifying genetic variations that impact surgical outcomes, this knowledge can guide decisions regarding the type and timing of surgery in patients with congenital heart diseases.

AI is rapidly transforming pediatric surgery, offering numerous applications across various subspecialties. AI technologies, including machine learning, computer vision, and natural language processing, are used for predictive analytics, decision support, preoperative planning, and surgical guidance. In pediatric orthopedics, AI-based tools such as BoneView, BoneXpert, and 3D printing technologies are improving diagnosis, imaging, and treatment planning. While AI holds great promise in enhancing clinical workflows and patient outcomes, challenges remain, including data privacy concerns, regulatory considerations, and the need for interdisciplinary collaboration. A systematic review revealed that most AI models in pediatric surgery focus on predictive, diagnostic, and decision-support applications, with neural networks and ensemble learners being the most commonly used methods. However, few published algorithms have undergone external validation, offer interpretability, or are free from bias, highlighting important areas for future research.

Head and Neck Surgery

Personalized medicine in head and neck surgery, particularly for squamous cell carcinoma, is rapidly advancing. Genetic profiling and biomarkers play a critical role in early diagnosis and risk assessment. Treatment approaches include targeted therapies, immunotherapy, and gene-editing techniques such as CRISPR/Cas9. However, the complex genomic landscape of squamous cell carcinoma presents challenges that necessitate combination therapies to achieve optimal outcomes. Preclinical research uses advanced 3D models and organoids to replicate the tumor microenvironment, facilitating the study of personalized treatments. Additionally, AI and machine learning are increasingly used to analyze large datasets and predict patient responses, thereby improving treatment strategies. These advances in personalized medicine offer promising prospects for improving diagnosis, treatment, and outcomes in patients undergoing head and neck surgery.

AI has emerged as a powerful tool in head and neck surgery, offering numerous applications in diagnosis, treatment planning, and outcome prediction. AI algorithms can analyze various data types, including imaging, voice, and clinical information, to improve diagnostic accuracy and support treatment decision-making. In oncology, AI assists in tumor segmentation, characterization, prognosis, and the prediction of metastasis and treatment response. Surgical applications of AI include margin assessment, complication evaluation, and identifying cases requiring salvage laryngectomy. AI also shows promise in enhancing histopathologic diagnoses, particularly for oral cancer and head and neck squamous cell carcinoma. While AI demonstrates significant potential for improving patient care, challenges remain, including the need for larger training datasets and the critical evaluation of AI-generated information by clinicians.

Otorhinolaryngology (ENT Surgery)

Personalized medicine in otorhinolaryngology, particularly in ear surgery, is gaining traction. In cochlear implantation, genetic assessments and advanced imaging techniques are employed to tailor surgical approaches and optimize outcomes based on individual patient characteristics. For chronic otitis media, researchers are investigating the role of allergies in its pathogenesis and the potential of immunotherapy as a personalized treatment approach. In chronic sinusitis, advances in informatics, microbiome research, and genomics enable more accurate predictions of surgical outcomes, thereby improving patient

selection for endoscopic sinus surgery. These developments reflect a broader shift in otorhinolaryngology toward personalized diagnostics and treatments, moving away from a one-size-fits-all approach. This trend is particularly significant given the high prevalence of hearing loss and the substantial healthcare costs associated with conditions such as chronic sinusitis.

AI is increasingly being applied in otorhinolaryngology, offering significant potential improvements in diagnosis, treatment, and patient care. Applications of AI include the automated detection of hearing loss, enhancement of hearing aid, speech restoration, and outcome prediction for cochlear implants. Machine learning algorithms analyze medical images, audio data, and clinical information, aiding in the diagnosis of various ENT conditions. AI also shows promise in improving surgical precision in head and neck surgeries. While AI technologies offer substantial benefits, challenges such as data security and privacy remain. Ethical considerations and the need for bias-free AI systems are also emphasized. Collaboration between ENT specialists and data scientists is essential for advancing AI technologies in this field.

Urology

Personalized medicine in urology aims to tailor treatments based on individual patient characteristics, particularly genetic profiles, and has made significant advances in various urologic cancers, including prostate, bladder, and renal cell carcinoma. In prostate cancer, androgen deprivation therapy represents an early form of targeted treatment; however, resistance frequently develops. Molecular profiling and biomarker identification are critical for developing personalized treatments for both bladder and prostate cancers. Imaging techniques such as PET/CT are being investigated to guide individualized treatment strategies, with promising targets including carbonic anhydrase IX in renal cell carcinoma and prostate-specific membrane antigen in prostate cancer. Researchers are actively engaged in both basic science and clinical applications to further advance personalized medicine in urology.

AI is emerging as a powerful tool in urology, with applications across various subspecialties. It can enhance diagnostic accuracy, optimize treatment strategies, and improve patient outcomes. In the management of kidney stones, AI predicts stone composition, while in benign prostatic hyperplasia, it assesses disease severity. For urologic cancers, AI assists in predicting treatment response, survival, prognosis, and recurrence based on genomic and biomarker studies. Machine learning algorithms show promise in improving prediction accuracy for bladder diseases, including interstitial cystitis and bladder cancer. Although AI holds significant potential for improving urologic care, ongoing research and clinical trials are essential to validate its effectiveness and facilitate its integration into routine practice.

Obstetrics and Gynecology

Personalized medicine in gynecologic oncology is an evolving field that aims to tailor treatments based on patients' molecular and genetic data. Recent advances in tumor profiling and the availability of large-scale databases have provided extensive molecular data, facilitating the development of targeted therapies such as VEGF inhibitors, PARP inhibitors, and cancer vaccines. Precision medicine approaches are applied across various aspects of women's healthcare, including diagnosis, treatment planning, and fetal identification in reproductive medicine. AI applications in obstetrics and gynecology include imaging interpretation, preterm birth detection, and surgical planning. Although AI cannot replace physicians, it can be integrated into clinical practice to support decision-making, reduce errors, and enhance overall care quality. Despite its potential, implementing AI in obstetrics and gynecology faces significant technical and ethical challenges. As research advances, AI is expected to play an increasingly significant role in gynecologic practice in the coming years.

Ophthalmology

Personalized medicine in ophthalmology is an emerging field focused on tailoring diagnosis, prognosis, and treatment to individual patients. It leverages advances in genomics, molecular diagnostics, and targeted therapies to improve patient care. Key areas of emphasis include disease classification through genetic and phenotypic assessments, as well as individualized patient management. Pharmacological biomarkers and therapeutic optimization are particularly critical in conditions such as age-related macular degeneration, diabetic macular edema, and glaucoma. Genetic testing can aid in predicting disease risk, establishing accurate diagnoses, and potentially forecasting treatment responses. Despite existing challenges, personalized ophthalmology has the potential to revolutionize the field through more precise screening, preventive measures, and customized treatments. Ongoing research continues to investigate genetic factors that influence disease development and treatment outcomes across various ophthalmic disorders.

AI is revolutionizing ophthalmology by enhancing diagnostic and therapeutic approaches for various eye conditions. Applications of AI, particularly deep learning, have shown significant promise in diagnosing and staging diseases such as diabetic retinopathy, age-related macular degeneration, and glaucoma. The availability of digital imaging techniques, such as optical coherence tomography, has facilitated the development of AI in this field. Although AI systems have demonstrated the potential to improve disease diagnosis and clinical decision-making, most remain in experimental stages, with only a few achieving clinical implementation. Key challenges include concerns about security and privacy, as well as the necessity for high-quality images and comprehensive training datasets. Despite these obstacles, the integration of AI in ophthalmology continues to progress, holding great promise for transforming patient care and disease management in the future.

Discussion

AI is poised to revolutionize personalized medicine by analyzing extensive biomedical data to tailor treatments for individual patients. Applications of AI in personalized medicine include genomic medicine, disease diagnosis, risk prediction, and patient classification. The convergence of AI and precision medicine promises to address complex healthcare challenges by integrating genomic and non-genomic factors with patient symptoms and clinical history. For AI systems in personalized medicine to be effective, they must demonstrate acceptable performance, interpretability, and clinical validity. Key factors for successful implementation include standardizing and collecting genetic and health data, utilizing multimodal data, collaborating with disease specialists, and conducting rigorous clinical research. However, ethical considerations such as privacy, informed consent, and fairness must be addressed to ensure the responsible implementation of AI in personalized healthcare.

Summary

The integration of AI in medicine, particularly in the field of personalized medicine, has made significant progress and is transforming healthcare. AI algorithms can analyze medical images, genetic data, and electronic health records to provide more accurate and timely diagnoses. By identifying individual patient characteristics and predicting treatment outcomes, AI facilitates the development of personalized treatment plans. Additionally, AI is used in robotic surgery, image-guided interventions, and surgical planning to enhance precision and improve outcomes. Despite its considerable potential, challenges such as data privacy concerns and the need for robust validation remain. This review examines the most important findings regarding the applications of AI in personalized medicine within surgical practice.

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Urology

Personalized medicine in urology aims to tailor treatments based on individual patient characteristics, particularly genetic profiles, and has made significant advances in various urologic cancers, including prostate, bladder, and renal cell carcinoma. In prostate cancer, androgen deprivation therapy represents an early form of targeted treatment; however, resistance frequently develops. Molecular profiling and biomarker identification are critical for developing personalized treatments for both bladder and prostate cancers. Imaging techniques such as PET/CT are being investigated to guide individualized treatment strategies, with promising targets including carbonic anhydrase IX in renal cell carcinoma and prostate-specific membrane antigen in prostate cancer. Researchers are actively engaged in both basic science and clinical applications to further advance personalized medicine in urology.

AI is emerging as a powerful tool in urology, with applications across various subspecialties. It can enhance diagnostic accuracy, optimize treatment strategies, and improve patient outcomes. In the management of kidney stones, AI predicts stone composition, while in benign prostatic hyperplasia, it assesses disease severity. For urologic cancers, AI assists in predicting treatment response, survival, prognosis, and recurrence based on genomic and biomarker studies. Machine learning algorithms show promise in improving prediction accuracy for bladder diseases, including interstitial cystitis and bladder cancer. Although AI holds significant potential for improving urologic care, ongoing research and clinical trials are essential to validate its effectiveness and facilitate its integration into routine practice.

Obstetrics and Gynecology

Personalized medicine in gynecologic oncology is an evolving field that aims to tailor treatments based on patients' molecular and genetic data. Recent advances in tumor profiling and the availability of large-scale databases have provided extensive molecular data, facilitating the development of targeted therapies such as VEGF inhibitors, PARP inhibitors, and cancer vaccines. Precision medicine approaches are applied across various aspects of women's healthcare, including diagnosis, treatment planning, and fetal identification in reproductive medicine. AI applications in obstetrics and gynecology include imaging interpretation, preterm birth detection, and surgical planning. Although AI cannot replace physicians, it can be integrated into clinical practice to support decision-making, reduce errors, and enhance overall care quality. Despite its potential, implementing AI in obstetrics and gynecology faces significant technical and ethical challenges. As research advances, AI is expected to play an increasingly significant role in gynecologic practice in the coming years.

Ophthalmology

Personalized medicine in ophthalmology is an emerging field focused on tailoring diagnosis, prognosis, and treatment to individual patients. It leverages advances in genomics, molecular diagnostics, and targeted therapies to improve patient care. Key areas of emphasis include disease classification through genetic and phenotypic assessments, as well as individualized patient management. Pharmacological biomarkers and therapeutic optimization are particularly critical in conditions such as age-related macular degeneration, diabetic macular edema, and glaucoma. Genetic testing can aid in predicting disease risk, establishing accurate diagnoses, and potentially forecasting treatment responses. Despite existing challenges, personalized ophthalmology has the potential to revolutionize the field through more precise screening, preventive measures, and customized treatments. Ongoing research continues to investigate genetic factors that influence disease development and treatment outcomes across various ophthalmic disorders.

AI is revolutionizing ophthalmology by enhancing diagnostic and therapeutic approaches for various eye conditions. Applications of AI, particularly deep learning, have shown significant promise in diagnosing and staging diseases such as diabetic retinopathy, age-related macular degeneration, and glaucoma. The availability of digital imaging techniques, such as optical coherence tomography, has facilitated the development of AI in this field. Although AI systems have demonstrated the potential to improve disease diagnosis and clinical decision-making, most remain in experimental stages, with only a few achieving clinical implementation. Key challenges include concerns about security and privacy, as well as the necessity for high-quality images and comprehensive training datasets. Despite these obstacles, the integration of AI in ophthalmology continues to progress, holding great promise for transforming patient care and disease management in the future.

Discussion

AI is poised to revolutionize personalized medicine by analyzing extensive biomedical data to tailor treatments for individual patients. Applications of AI in personalized medicine include genomic medicine, disease diagnosis, risk prediction, and patient classification. The convergence of AI and precision medicine promises to address complex healthcare challenges by integrating genomic and non-genomic factors with patient symptoms and clinical history. For AI systems in personalized medicine to be effective, they must demonstrate acceptable performance, interpretability, and clinical validity. Key factors for successful implementation include standardizing and collecting genetic and health data, utilizing multimodal data, collaborating with disease specialists, and conducting rigorous clinical research. However, ethical considerations such as privacy, informed consent, and fairness must be addressed to ensure the responsible implementation of AI in personalized healthcare.

Summary

The integration of AI in medicine, particularly in the field of personalized medicine, has made significant progress and is transforming healthcare. AI algorithms can analyze medical images, genetic data, and electronic health records to provide more accurate and timely diagnoses. By identifying individual patient characteristics and predicting treatment outcomes, AI facilitates the development of personalized treatment plans. Additionally, AI is used in robotic surgery, image-guided interventions, and surgical planning to enhance precision and improve outcomes. Despite its considerable potential, challenges such as data privacy concerns and the need for robust validation remain. This review examines the most important findings regarding the applications of AI in personalized medicine within surgical practice.

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