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MINI REVIEW

Revolutionizing Healthcare Paradigms: The Integral Role of Artificial Intelligence in Advancing Diagnostic and Treatment Modalities

Chin-Lung Kuo, MD, PhD[1,2,3*]

[1] Department of Otolaryngology-Head and Neck Surgery, Taipei Veterans General Hospital, Taipei, Taiwan
[2] Institute of Brain Science, National Yang Ming Chiao Tung University, Taipei, Taiwan
[3] Department of Otolaryngology, School of Medicine, National Yang Ming Chiao Tung University, Taipei, Taiwan

ABSTRACT

This article examines the profound impact of artificial intelligence (AI) on the future of healthcare, emphasizing its potential to revolutionize key areas such as diagnostics, treatment, and patient care. It anticipates significant cost reductions and advocates for a shift in healthcare strategy, urging a proactive approach to disease prevention rather than solely focusing on treatment once they manifest. The article elucidates critical advancements in robot-assisted surgery, AI-driven virtual nursing, and efficient healthcare data management. These advancements collectively aim to enhance medical outcomes and promote patient-centric care. Additionally, the article addresses the challenges and ethical considerations inherent in integrating AI into healthcare, including its impact on clinical skills, the imperative of preserving empathy in patient care, and the potential to exacerbate health inequities. Providing a comprehensive analysis, the article serves as an invaluable resource for those seeking to understand the intricate relationship between AI and healthcare. It advocates for a balanced approach that harmonizes technological advancement with the core principles of healthcare.

INTRODUCTION

Artificial Intelligence (AI) is a dynamic and rapidly evolving field within computer science. AI involves developing sophisticated computers capable of learning and demonstrating intelligence that parallels human cognition. The foundation of AI technology lies in algorithms that enable machines to autonomously learn from experience. This learning process is facilitated through iterative adjustments as the system repeatedly executes tasks. Contemporary AI systems have advanced significantly, excelling in areas like deep learning and natural language processing. These advancements owe much to their exceptional pattern recognition abilities and the capacity to analyze and interpret extensive datasets.

The integration of AI into the healthcare sector is advancing rapidly, heralding transformative changes in diagnostics and treatment with the progression of AI and robotics. Significant advancements are foreseen in robot-assisted surgery, clinical tasks, AI-assisted virtual nursing, and administrative procedures. The incorporation of AI in healthcare is projected to yield substantial cost reductions, potentially saving up to $150 billion annually for the US healthcare system by 2026 [1]. These savings are rooted in a shift from a reactive approach to disease treatment to a proactive stance on health management, potentially resulting in fewer hospital admissions, reduced doctor visits, and diminished treatment requirements. AI is poised to assume a pivotal role in continuous health monitoring and coaching, thereby enabling earlier diagnoses, the development of personalized treatment plans, and the enhancement of follow-up care efficiency. This evolution in healthcare is not solely anticipated to streamline processes but also to significantly improve patient outcomes [1–4].

In the envisioned future of healthcare, the integration of a personal health dashboard represents a paradigm shift toward more autonomous health management. Such systems could significantly alleviate the burden on healthcare facilities by minimizing unnecessary visits, thereby optimizing healthcare resource allocation. Additionally, the real-time data collected could contribute to large-scale health studies, enhancing our understanding of diseases and their patterns [4].

The adoption of algorithmic methods in diagnosis and treatment is poised to spur the development of more advanced AI tools, potentially leading to significant breakthroughs in our understanding of complex medical conditions. Moreover, the integration of genomic data with the medical histories of patients in diagnostic processes promises a new era of personalized medicine. In this approach, treatments would be tailored not only to the specific disease but also to each patient's unique genetic profile, offering a more targeted and effective healthcare solution [4].

AI IN MEDICINE: A DUAL APPROACH

The futuristic landscape of AI in healthcare, replete with vast possibilities, is rapidly materializing. AI applications in this field can be broadly classified into two categories: physical and virtual.

The physical aspect of AI encompasses the tangible hardware utilized in healthcare settings. This includes robots aiding in surgeries, tracking devices for patient monitoring, and a variety of sensors and other medical devices [2]. Looking forward, the field anticipates the advent of nanorobots, which are expected to revolutionize drug delivery, especially in targeting specific areas like tumors. This technology aims to concentrate higher drug doses directly at the target sites while enabling precise control over drug release [5].

On the other hand, the virtual aspect of AI primarily involves the processing and management of diverse data sets, including the integration of electronic health records with medical research. It utilizes advanced techniques such as deep learning to create efficient health management systems. Virtual AI applications also play a crucial role in linking individual patient cases with global medical research, thus providing physicians with informed guidance on optimal treatment strategies and facilitating access to a wealth of global healthcare resources.

PHYSICAL ASPECTS OF AI IN HEALTHCARE

The physical aspect of AI in healthcare is a critical component, encompassing a wide range of devices and hardware utilized by healthcare professionals. These tools are instrumental in delivering care and enabling remote patient monitoring. This category includes advanced robotics used in surgeries, wearable health monitors, and various other diagnostic and therapeutic devices. These technologies not only facilitate more efficient and precise medical interventions but also extend the reach of healthcare services, allowing for continuous patient monitoring and care management, even from a distance. In this section, we will explore the various hardware and devices that constitute the physical dimension of AI in healthcare, examining their roles and the impact they have on the healthcare ecosystem.

Robot-Assisted Surgery

AI has catalyzed significant advancements in the realm of robot-assisted precision surgery. AI systems enhance surgical accuracy and efficiency by integrating a wealth of information, including diagnostic data, medical records, and real-time operating metrics. Surgeons can access and utilize historical data from surgeries conducted globally, gaining insights and recommendations based on the latest international developments in their field.

Robot-assisted surgery has demonstrated a notable superiority over traditional laparoscopic methods, particularly for surgeons who frequently employ this technique. This modern approach not only reduces the physical and mental strain on surgeons but also offers significant benefits to patients when compared to conventional procedures. Research in various medical specialties, such as general surgery and surgical oncology, indicates that patients undergoing robot-assisted surgery typically experience less postoperative pain, have a lower likelihood of requiring conversion to open surgery, and benefit from a faster recovery period compared to those undergoing standard laparoscopic surgery [6,7].

A study focusing on recurrent inguinal hernia repairs has revealed significant differences in the need for postoperative pain medication, depending on the surgical method employed. Notably, only 45.3% of patients who underwent robotic surgery required pain medication after the procedure, a considerably lower rate compared to those in the laparoscopic (65.4%) and open surgery (80%) groups. However, an important factor to consider is the duration of the surgery: robotic surgeries take longer on average, approximately 83 minutes, in contrast to the typical 65 minutes for laparoscopic procedures [8]. This finding highlights the trade-offs involved in choosing between different surgical methods, considering both operation time and postoperative recovery.

In abdominoperineal resections for colorectal cancer, robotic surgery has shown a significant reduction in complication rates, reporting 13.2% compared to 23.7% in laparoscopic methods. Additionally, it has achieved zero conversions to open surgery and shorter hospital stays, averaging 5 days versus 7 days for laparoscopic surgeries. Importantly, these improvements do not compromise the long-term outcomes of cancer treatment. This emphasizes the efficacy and safety of robotic surgery in handling complex medical procedures [9].

Robot-assisted systems have become increasingly valuable in the realm of minimally invasive surgery, particularly in enhancing pain management and reducing complications. While laparoscopic procedures, characterized by small incisions for inserting a camera or surgical instruments, are a prevalent form of machine-assisted surgery, robot-assisted surgery addresses several limitations inherent to this approach. These limitations include challenges in hand-eye coordination and the constraints posed by traditional surgical instruments. Robot-assisted surgery employs a remote guidance system, often integrated with artificial intelligence, to control surgical instruments with high precision. This system uses intuitive controls to improve the surgeon's coordination between hand movements and visual feedback [10]. Such technological advancements have significantly revolutionized surgical procedures, making them more efficient and safer for patients.

AI holds significant promise in augmenting surgical methods through the application of insights garnered from worldwide data, potentially leading to enhancements in patient care characterized by heightened accuracy and efficiency. However, concerns regarding the financial implications and the general accessibility of these technological developments persist. Addressing the challenges associated with the expense and reach of robot-assisted surgeries is crucial to promote equitable healthcare. Approaches to accomplish this include advocating for policy reforms that support funding and insurance provisions for these technologies, committing to the development of cost-efficient surgical robots, and engaging in global partnerships for the sharing of expertise and resources. Moreover, the establishment of training initiatives across varied geographic and socioeconomic settings is essential in making these sophisticated surgical approaches universally accessible.

Despite facing several technical challenges and complications in its current stage, the field of robotic surgery is on a path of continuous development. This ongoing progress is anticipated to bring about increased sophistication in robotic surgical systems. Such advancements are poised to usher in a new era of robotic surgery, characterized by enhanced precision, safety, and efficiency in surgical procedures [11].

Wearable Trackers in Patient Monitoring

The advent of wearable devices and trackers, such as FitBit, Apple, and Garmin, has made real-time patient monitoring increasingly feasible. These devices are equipped with sensors that harness AI technology to collect and process various health-related data, including electroencephalogram) and electrocardiogram signals. They can communicate with one another and with a central server, thereby forming an interconnected network [12]. AI systems play a crucial role in analyzing this continuous data stream, offering suggestions for health-related actions, and detecting any irregularities in the collected data.

The integration of wearable healthcare sensors with AI systems has been instrumental in the development of electronic skin (e-skin) and ultra-sensitive, flexible, stretchable sensors made from organic materials. These innovative technologies are designed to be comfortably worn by patients, offering minimal discomfort while providing continuous health monitoring [13].

Innovative technologies are being developed to aid in the care of the elderly and individuals with cognitive challenges. This includes mobile robots, intelligent walkers, and handheld computers that wirelessly communicate with a base station, providing essential support to those with physical or cognitive infirmities. These systems integrate AI for continuous monitoring and communication, enhancing the safety and independence of users. Activity guidance systems prove to be invaluable for individuals with cognitive impairments, aiding in daily tasks and navigation [14]. Additionally, advanced surveillance systems equipped with motion-activated or infrared sensors are increasingly used in hospital settings. These systems monitor patient activities and environments, automatically generating detailed reports for healthcare providers [15].

Wearable monitoring and alert systems have become invaluable tools in managing patients at high risk of cardiac and/or respiratory difficulties. These devices are designed to continuously collect and transmit vital physiological data, including vital signs, to medical centers for real-time monitoring. Particularly noteworthy are the unobtrusive wrist-worn devices, which enable long-term monitoring. Their design ensures that patients' mobility and daily activities are not hindered, thus maintaining their quality of life while under constant medical supervision [16].

Radio frequency identification devices (RFID) are increasingly employed in healthcare settings for identifying patients and generating online laboratory data and radiology reports through handheld wireless personal digital assistants (PDAs). These RFID systems are instrumental in optimizing admissions processes and enhancing the monitoring of emergency areas. Their integration into healthcare operations not only improves administrative efficiency but also ensures quicker access to critical patient information, thereby facilitating timely and effective medical care [17].

The integrated software-hardware system known as MASCAL utilizes tagging technology to track patients, equipment, and staff during mass casualty events, situations where medical resources are under high demand. By providing real-time tracking and management capabilities, this system significantly optimizes efficiency and resource allocation during critical incidents. Its deployment ensures a more coordinated and effective response, essential for managing large-scale medical emergencies [18].

The increasing prevalence of AI-powered wearable devices for real-time patient monitoring marks a significant advancement in both patient care and data collection. These devices offer substantial benefits, yet they also bring forth concerns related to patient privacy. To protect patient data effectively, it is essential to apply strict data protection policies. This involves the adoption of advanced encryption techniques, the enforcement of rigorous access controls, and the conduct of frequent security audits to ensure data safety. Equally important is the education of patients regarding their data privacy rights and the necessity of obtaining informed consent for the use of their data. These measures are critical for the ethical and secure employment of such technologies in healthcare.

Advancements in Home Care Technology

Home care units typically consist of a portable medical device integrated with a tablet personal computer. These systems are specifically designed to monitor critical clinical data, including blood oxygen saturation, heart rate, breathing rate, and movement, all without restricting patients' movement within their homes. The collected data is periodically transmitted to a service center, where it undergoes analysis by healthcare professionals. A significant study that explored the home care of brain-injured children revealed encouraging results: 78% of the patients and their families involved in the study reported finding the system highly beneficial [19].

These home care systems have also proven effective in monitoring patients with asthma. In one study, an automated system based at home was used to monitor symptoms through a personal digital assistant (palmtop) with internet connectivity [20].

Additionally, researchers have developed an implantable hemodynamic monitor that transmits data to a central server for doctor analysis. The findings from this study underscored the system’s feasibility and user-friendliness in the telemonitoring of hemodynamic data, demonstrating significant potential in remote patient care [21].

The advancement of home care units, particularly in the monitoring of critical health data for conditions such as asthma and brain injuries, represents a significant stride in healthcare technology. Nevertheless, it is crucial to address the digital divide. It is vital to ensure that individuals in remote or underserved areas, who may lack the same level of technical knowledge or infrastructure, can access these technologies. Bridging this gap in home care technology necessitates the development of user-friendly and cost-effective solutions. Collaborating with government and non-profit organizations can help distribute these technologies to underserved areas. Additionally, offering training and support services ensures that all individuals, regardless of their technological proficiency or location, can reap the benefits of these advancements.

VIRTUAL ASPECTS OF AI IN HEALTHCARE

The virtual aspect of AI in healthcare refers to the intelligent management of data, which assists physicians. AI-assisted systems are already in place to manage the enormous volume of medical data generated daily, including X-rays and CT scans. Radiology reports stored in various institutions can be accessed through machine learning techniques, utilizing large, multi-institutional repositories of these reports [22]. Additionally, AI technology plays a significant role in administrative tasks, diagnostics, and virtual consultations.

Administrative Work in Healthcare Systems

Healthcare systems generate extensive data, including patient records, medical histories, and treatment plans. Contemporary AI systems possess the ability to collect, store, format, and retrieve this data efficiently. This symbiotic relationship between healthcare and AI simplifies data management, providing healthcare practitioners and service providers with more time for critical tasks.

AI expedites responses to medical emergencies by enabling swift data accessibility and analysis. Furthermore, it streamlines administrative processes, particularly in the generation of precise digital invoices, thereby improving financial operations in healthcare facilities. In summary, the integration of AI into healthcare data management enhances efficiency, benefiting practitioners and patients alike.

Diagnosis and Treatment

Accurate diagnosis often relies on a physician’s experience. However, even seasoned medical professionals can find it challenging to accurately diagnose uncommon or rare conditions [23–26]. AI algorithms excel in analyzing and correlating similar case histories globally, processing large data sets far beyond human capability. These algorithms can assimilate information from trials and treatments used in comparable cases, effectively linking a patient's case history with the latest research. This capability greatly simplifies the process of identifying patterns and making predictions that would be difficult, if not impossible, for humans. Additionally, AI plays a crucial role in reducing the likelihood of misdiagnoses, to which individual doctors are susceptible. This reduction in error helps prevent delays, unnecessary testing, and potentially harmful treatments [1,4,27].

Many AI systems are already in use to assist in diagnosis and treatment. The diagnostic clinical decision support system, VisualDx, enhances diagnostic accuracy and aids in therapeutic decision-making by correlating medical images with patient symptoms [28]. IBM’s Watson for Oncology employs cognitive computing technology to review medical literature, patents, genomics, and other data. It has the capacity to understand scientific terminology and analyze millions of pages swiftly. The success of pilot studies has shown Watson’s potential in drug target identification and in aiding oncologists by recommending innovative treatments through the correlation of patient data with global medical journals [29]. This method of analysis is based on case-based reasoning (CBR), a process where new problems are addressed by applying solutions from past cases. AI systems employing CBR can continually learn from these previous cases [30].

Analyzing Tests With AI

AI is particularly adept at handling repetitive tasks, such as test analysis. Current software applications are capable of interpreting CT scans and other medical images, making rapid comparisons with extensive image databases, a task that takes human technicians considerably longer. In the future, AI is expected to become an ubiquitous virtual assistant for doctors and nurses in all medical fields. While cardiology and radiology are currently poised to benefit the most from these advancements, it's anticipated that intelligent systems will eventually aid in a broad spectrum of testing procedures. These systems may even evolve to independently recommend treatments.

Personal Consultation via AI

AI systems have evolved remarkably, serving as virtual companions and consultants for patients. These advanced systems facilitate human-like medical consultations in remote, non-centralized locations. Various apps are now capable of conducting medical consultations, considering the patient's medical history. An example is Babylon, an app designed to triage patients based on their reported symptoms. It offers potential diagnoses and recommended actions by comparing symptoms with a comprehensive database of illnesses. Furthermore, this system incrementally learns from other cases, ensuring that doctors and clinicians are equipped with the most current medical techniques [3].

Virtual Nurses in Pocket-Sized Apps

Several apps now function as virtual nurses, conveniently accessible in a patient's pocket. One notable example is Molly, a digital nurse developed by Sensely. This app monitors patient conditions and facilitates connections with clinical services. Molly is designed to interact with patients, responding in a manner akin to a real nurse, which has led many patients to feel as though they are conversing with an actual person. The app allows patients to send images and messages for analysis by a clinical team. Furthermore, these apps can automatically gather data from various instruments and communication devices, providing a comprehensive overview of the patient's health status. As technology advances, we can anticipate algorithms that will not only offer automatic diagnoses but also provide patients with advice based on their physiological data [31].

Medication Monitoring Through Apps

The use of apps for monitoring patients' medication intake is becoming increasingly prevalent. A prime example is the AiCure app (https://aicure.com), which employs the smartphone's camera to verify the medications patients take, while also providing reminders for timely intake. This feature is notably advantageous for those dealing with serious medical conditions, ensuring consistent medication adherence. Additionally, the effectiveness of such apps in decreasing the frequency of hospital visits has been established, which helps in reducing the overall burden on healthcare resources.

Data Mining in Healthcare Through AI

One of the most prevalent applications of AI in healthcare is in data mining. This process involves integrating data from diverse sources, such as medical records, imaging studies, and genetic information. AI algorithms then analyze this integrated data to uncover connections and patterns. These insights are invaluable in aiding the diagnosis and treatment of patients, enabling healthcare professionals to make more informed decisions based on a comprehensive understanding of a patient's health profile [32].

Accelerating Drug Development With AI

AI has significantly reduced the time and costs associated with developing new drugs. A notable example of this was during the Ebola epidemic, when AI was employed to swiftly scan and redesign existing medications. Utilizing the technology available at that time, the process was condensed to a mere day — a stark contrast to the several months it traditionally required. This marked acceleration not only exemplifies the efficiency of AI but also underscores its potential to revolutionize the field of drug development.

AI in Genetic Medicine

AI applications are increasingly being utilized to process large volumes of genetic and DNA data, enhancing our ability to assess the likelihood of disease occurrence [33]. This advancement holds the promise of enabling early prediction of cancers and other life-threatening diseases, paving the way for proactive prevention strategies. A significant outcome of this development is the potential for creating cancer medications that are personalized to an individual's genetic profile and the specific genome of their tumor [34]. Furthermore, AI is poised to play a crucial role in identifying new disease genes, mutations associated with diseases, and discovering drug targets and biomarkers for complex diseases [35].

Artificial Neural Networks in Healthcare

Artificial neural networks (ANNs) simulate the learning process of the brain's neurons by forming connections and adapting to new situations. Capable of handling multiple data streams through extensive parallel processing, these networks are at the forefront of emerging technologies with significant potential in healthcare applications [36–38].

As a subset of machine learning, ANNs are dynamic, adaptive, and computational frameworks designed to mirror the structure and functionality of the human brain. They are trained to recognize and classify complex patterns in diseases, learning iteratively and progressively. Once adequately trained, ANNs often surpass traditional statistical methods in prediction accuracy. Their proficiency in understanding intricate, non-linear relationships between predictive factors and health outcomes has cemented their role in clinical decision support systems, substantially improving these systems' efficacy and reliability [39–41].

Crowd Sourcing and Social Media in Healthcare

The primary influence of AI in healthcare is evident in the way it revolutionizes information gathering and sharing. By monitoring social media platforms, AI can detect trending health-related discussions and facilitate connections among individuals, enabling them to exchange treatment experiences and options. Platforms like Twitter and Facebook are increasingly utilized for pharmacovigilance, which involves sourcing information about drug trials and effects. Furthermore, the pharmaceutical industry is leveraging AI to streamline the initial screening of drug compounds, helping to identify which drugs may be more effective for individual patients [42,43].

The use of AI tools for tracking social media has significant potential in predicting and monitoring epidemics before they escalate into serious threats. For instance, an existing computer algorithm successfully identified an Ebola outbreak nine days prior to its official report by the World Health Organization. This early detection was made possible by meticulously analyzing data from social media platforms, news reports, and government websites. Such capabilities demonstrate the critical role AI can play in enhancing global health security by providing timely alerts and facilitating prompt response to emerging health crises.

CHALLENGES IN AI-DRIVEN HEALTHCARE

While the integration of AI and data science in healthcare promises significant advancements, it also introduces critical challenges. One concern is the potential shift in medical education focus towards data science, which might inadvertently lead to the undervaluing of traditional clinical skills and the doctor-patient relationship. The increasing reliance on algorithms and data risks diminishing the empathy and personal touch in healthcare, both of which are essential for patient satisfaction and trust.

Furthermore, the implementation of technology-intensive healthcare systems has the potential to worsen preexisting health inequalities, particularly in areas with restricted access to advanced technology and internet connectivity. These concerns highlight the importance of adopting a balanced approach that leverages technological innovations while steadfastly upholding the fundamental values of healthcare [4].

It is crucial to recognize that AI is a tool to augment, rather than replace, the intuition and expertise acquired through clinical practice. Strategies for integrating AI into healthcare should focus on collaborative decision-making, where AI offers data-driven insights and healthcare professionals contribute their judgment and experience. This synergy can enhance patient-centric care without devaluing human medical expertise.

AI enhances healthcare efficiency by managing large volumes of medical data, facilitating diagnosis, streamlining administrative tasks, and enabling virtual consultations. However, risks of data inaccuracies and biases in AI algorithms exist. Ensuring these systems are accurate and fair, especially for diverse patient populations and conditions, is critical. This requires thorough testing and validation on diverse datasets to prevent biases. Ongoing algorithm monitoring and updates are necessary to maintain accuracy and incorporate new medical knowledge. Additionally, ethical frameworks and guidelines are essential to ensure responsible and equitable use of AI in healthcare.

AI integration in healthcare notably engenders ethical dilemmas, encompassing its influence on clinical competencies, the imperative of preserving empathy in patient interactions, and the potential exacerbation of healthcare disparities. Addressing these issues necessitates the formulation of unambiguous guidelines and ethical norms for AI deployment in the healthcare sector. This process should include the assurance of transparency, comprehensibility, and rigorous evaluation and validation of AI systems. Moreover, educating healthcare practitioners in the utilization and collaboration with AI technologies is crucial for sustaining empathy and the human element in patient care. Furthermore, proactive strategies and investments are imperative to forestall the amplification of health disparities resulting from inequitable access to AI innovations.

AI accelerates drug development and is pivotal in genetic medicine for disease prediction and treatment personalization. However, ethical issues like genetic profiling and discrimination arise. Addressing these concerns in AI-enabled genetic medicine necessitates a comprehensive strategy. Key steps include setting definite ethical standards for genetic data use, guaranteeing informed patient consent, and enforcing privacy protections. Moreover, establishing anti-discrimination policies related to genetic information is crucial. Collaborating with ethicists, legal professionals, and community leaders is essential for the ethical and responsible application of AI in genetic medicine.

CONCLUSIONS

The advancement of AI in medicine is contingent upon the development of integrated systems that encompass diverse data sources, biomedical informatics, knowledge-based tools, applications, and health policy. This also includes the establishment of robust biomedical networking infrastructures for efficient communication and data exchange. While there are apprehensions about AI potentially replacing doctors, these concerns are largely unfounded. Humans will continue to play an indispensable role in healthcare, with AI serving as an assistant that enhances the accuracy of diagnoses and the effectiveness of treatments. Emulating neural networks, AI-driven computer programs are set to become increasingly efficient. For AI to reach its full potential in healthcare, its implementation must be strategically aligned with data and clinically relevant knowledge. This involves integrating machine learning with clinical decision support systems to facilitate precise, cost-effective, and personalized healthcare solutions.

ARTICLE INFORMATION

***Correspondence:** Chin-Lung Kuo, MD, PhD, Department of Otolaryngology-Head and Neck Surgery, Taipei Veterans General Hospital, No.201, Sec. 2, Shipai Rd., Beitou District, 11217 Taipei City, Taiwan. Email: drkuochinlung@gmail.com

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