Research Article

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The Impact of Artificial Intelligence on Innovative Nanotechnologies for Advanced Medical Diagnosis

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Abstract

Artificial Intelligence (AI) is a technological domain wherein computer systems emulate human cognitive capabilities to execute tasks previously reliant on human intellect. Referred to as smart machines, these entities exhibit the intelligence to autonomously perform cognitive functions. Nanotechnology is a multidisciplinary field spanning science, technology, and engineering, focusing on activities at the nanoscale for industrial and research applications. The intersection of AI and nanotechnology has notably influenced the evolution of medical diagnosis, enhancing the quality of diagnostic devices through advanced material construction and heightened functional sophistication. This collaboration has positively impacted medical diagnostics, enabling devices to detect and diagnose conditions with greater precision and depth. The incorporation of nanoscale materials has contributed to heightened device sensitivity, while AI-driven functionalities have elevated diagnostic capabilities, marking a significant stride in advancing healthcare technologies. This paper will review the impact of artificial intelligence on innovative nanotechnologies for advanced medical diagnosis.

Keywords: Nanotechnology; Artificial intelligence (AI); Advance medical diagnosis

Introduction

Modern scientific and technological development increasingly relies on nano, biological and information sciences. For more than a decade, the thought that the convergence of nanotechnology, artificial intelligence (AI) and biology will promote another technical and scientific revolution has been lingering. Nanotechnology combines the knowledge of physics, chemistry and engineering, while AI has heavily relied on biological inspiration to develop some of its most effective paradigms such as neural networks or evolutionary algorithms.[1]. The huge generation of data, in multiple fields of health and materials science, that are now being well organized and stored, has deemed the development of advanced computational methods for their exploitation inevitable [2]. Machine learning algorithms were from the very beginning designed and used to analyze medical datasets[3]. Cheminformatics research has already contributed enormously to solve a number of problems in the drug discovery field, such as receptor binding or inhibition and surface protein interactions, and is continuously growing and adapting to the specific needs arising in different research domains such as nano safety [2]. These are mainly based on the artificial intelligence (AI) technologies that have made a significant contribution. These automatized technologies have been used as powerful tools in predicting the diagnosis and helping the clinicians in treatment planning [4]. According to a study from researchers at Johns

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Hopkins University, 40,500 patients die in intensive care units each year in the United States as a result of diagnostic errors. System-related factors, such as poor processes, teamwork, and communication were involved in 65 % of these cases. It is anticipated that routine application of AI will decrease the risk of such errors. Such advanced technology may ultimately replace a substantial percentage although certainly not all of the work physicians do on a daily basis [5]. Medical diagnosis is the final stage of a patient centered process where physicians collaborate with patients to reason backward to determine a trend of previous health conditions that could be a potential cause of the patient's current health situation. The accuracy of this process is crucial to the patient's survival and evaluation of the physician's ability to make sound clinical decisions. In the past, it was mainly human driven with physicians using analytical, non-analytical and experience to arrive at diagnosis which sometimes was heavily influenced by biases. The advent of information technology and its applications in medicine has improved clinical reasoning and judgement and enhanced the quality of healthcare as a result. However, with the complexities of human health and sophistication of medicine, there is the need for more advanced methods for medical diagnosis. This paper will review the impact of artificial intelligence on innovative nanotechnologies for advanced medical diagnosis.

Nanotechnologies for medical diagnosis

Nanomedicine is the term used to refer to the applications of nanotechnologies in medicine and healthcare. Specifically, nanomedicine uses technologies at the nanoscale and nano-enabled techniques to prevent, diagnose, monitor and treat diseases [6]. For medicine especially, building tiny molecular-scale devices capable of delivering drugs specifically to areas of disease can make conventional pharmaceuticals more efficacious and decrease their adverse side effects[7]. Drug discovery is only one of the many areas in healthcare that nanotechnology is now benefiting. The current and promising applications of nanomedicine include, but are not limited to drug delivery, in vitro diagnostics, in vivo imaging, therapy techniques, biomaterials, and tissue engineering[8]. Although the application of nanotechnology to medicine appears to be a relatively recent trend, the basic nanotechnology approaches for medical application date back several decades. The first example of lipid vesicles which later became known as liposomes were described in 1965; the first controlled release polymer system of macromolecules was described in 1976; the first long circulating stealth polymeric nanoparticle was described in 1994; the first quantum dot bioconjugate was described in 1998; and the first nanowire nanosensor dates back to 2001[9]. Nanosensor is a sensing device with at least one dimension of 100 nm used to gather information on the nanoscale and convert it into data for analysis. In public places, nanosensors are used to track the propagation of viruses and illnesses. Some applications include real-time blood, illness, and breath testing in-body networks [10].

A biosensor is an analytical device that contains a biological component that gives the device specificity and produces a response that is transduced by the physical component into an electrical or optical signal. Biosensors can be used to diagnose a variety of factors such as cancers or neurological diseases, infections, poisoning, toxic agents, and even drugs. Earlier biosensors were widely used for detection of diseases and metabolic disorders from serum biomarkers like DNA, RNA, antigens/antibodies, enzymes, a fragment of protein, etc. Nowadays, a variety of studies have shown that the application of nanomaterials with biomarkers in diagnostic sensors increases the detection power. Cancer biomarkers are often protein substances that have a higher concentration in cancerous conditions than normal conditions. They are also commonly used as an index for cancer prognosis, diagnosis of various stages, and as an indicator of cancer severity. Transmission without damage of cancer biomarkers on diagnostic sensors which is related to the type of nanoparticle and transmission method can significantly improve their bioavailability and diagnostic value [11].

The emergence of micro/nanorobots promotes the development of a precision medicine, which is an important direction of modern biomedical development. Micro/nanorobots refers to the functional devices that can realize motion at micron and nanoscale, driven by a light field, magnetic field, and sound field[12]. These tiny robotic surgeons could give us access to remote and hard to reach sections of the body and perform diverse medical procedures. Micro/nanorobots have potential in medical diagnosis, by isolating pathogens or measuring physical proprieties of tissue in real-time allowing to obtain a precise diagnosis of disease and vital signals[13]. The micro/nanorobot sensing strategy relies on the motility of artificial nanomotors, functionalized with different bioreceptors through the sample to realize "on-the-fly" specific biomolecular interactions. Such receptor-functionalized micro/nanomotors offer powerful binding and transport capabilities that have led to new routes for detecting and isolating biological targets, such as proteins, nucleic acids, and cancer cells, in unprocessed body fluids [14]. To achieve precise delivery of therapeutic payloads to targeted disease sites, drug delivery vehicles are desired to have some unique capabilities, including a propelling force, controlled navigation, cargo-towing and release, and tissue penetration. Although these remain unmet challenges for current drug delivery systems, micro/nanorobots represent a new and attractive class of delivery vehicles that can meet these desirable features. The motor-like micro/nanorobots have the potential to rapidly transport and deliver therapeutic payloads directly to disease sites, thereby improving the therapeutic efficacy and reducing systemic side effects of highly toxic drugs[14] Pharmacytes are the nanorobots designed for the action of drug delivery. The dosage of drug will be loaded

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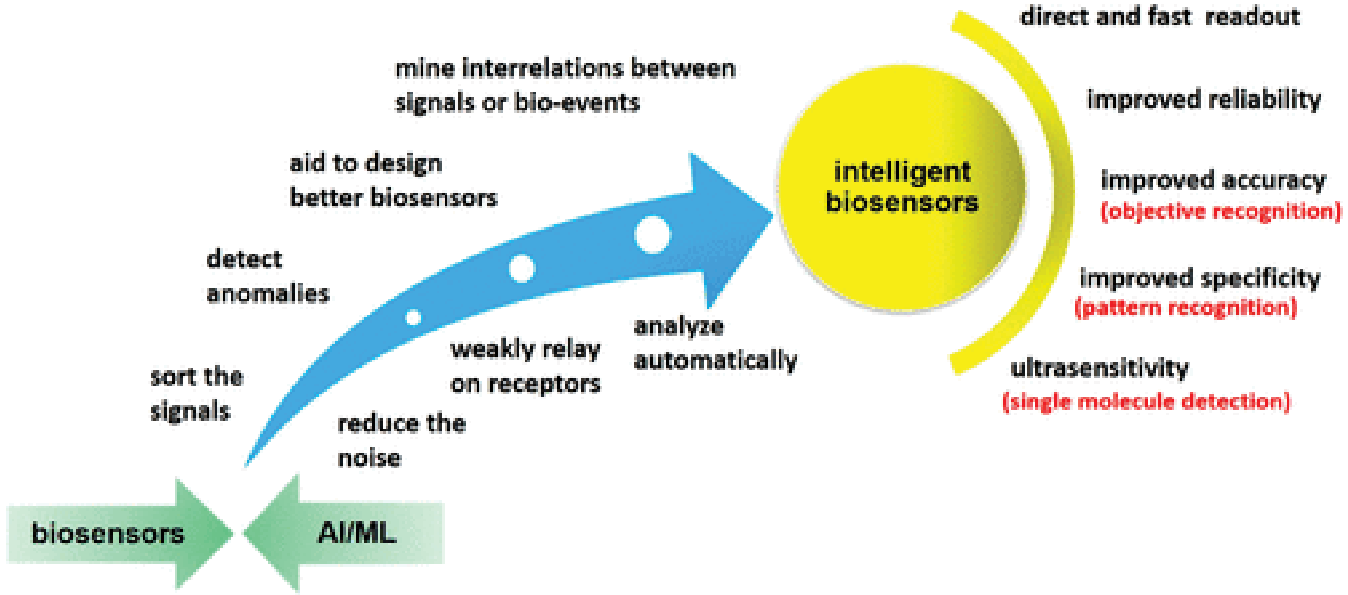
into the payload of the pharmacyte. The pharmacyte will be capable of precise transport and targeted delivery of drug to specific cellular targets. The pharmacytes upon arriving at the vicinity of tumor or any target cell would release the drug via nanoinjection or by progressive cytopenetration until the payload delivery is reached [15]. The application of nanotechnology can improve the drug solubility, change the drug distribution in various tissues and organs, adjust the release rate to obtain sustained release and controlled release profiles, and promote the drug aggregation in its target[16].

AI and medical diagnosis

Modern medicine is faced with the challenge of acquiring, analysing and applying the large amount of knowledge necessary to solve complex clinical problems. The development of medical artificial intelligence has been related to the development of AI programs intended to help the clinician in the formulation of a diagnosis, the making of therapeutic decisions and the prediction of outcome. They are designed to support healthcare workers in their everyday duties, assisting with tasks that rely on the manipulation of data and knowledge[17]. The application of AI in medicine has two main branches: virtual and physical. The virtual component is represented by Machine Learning, that is represented by mathematical algorithms that improve learning through experience. There are three types of machine learning algorithms: (i) unsupervised (ability to find patterns), (ii) supervised (classification and prediction algorithms based on previous examples), and (iii) reinforcement learning (use of sequences of rewards and punishments to form a strategy for operation in a specific problem space) and the second form of application of AI in medicine includes physical objects, medical devices and increasingly sophisticated robots taking part in the delivery of care (carebots)[18]. Fundamentally, ML uses algorithms to parse data, learn underlying patterns, and offer insights using which decisions and predictions about real-world events can be made. Unlike traditional hard-coded software programs that solve specific tasks, ML uses large amounts of data to “train” and apply algorithms to dynamically learn how certain tasks can be accomplished. Most research on clinical cancer is currently aimed at predicting the correct outcome in response to treatment. If the prognoses of different patients can be predicted more accurately, more precise, and suitable treatments can be provided to them; in fact, such treatments tend to be individualized or customized to patients. To date, accurate treatment customized for a patient is very difficult to implement. However, AI can be used to process and analyze multi-factor data from multiple patient examination data to predict cancer prognosis as well as the survival time and the disease progress of patients more accurately[19].

AI and Nanotechnologies for medical diagnosis

The study on tumor-killing nanorobots keeps moving forward, accompanied by increasingly mature designs of nanorobots, leading to more effective and accurate early-stage clinical cancer diagnosis [20]. The various components in nanorobot include power supply, fuel buffer tank, sensors, motors, manipulators, onboard computers, pumps, pressure tanks and structural support. The medical nanorobots with chemical biosensors can be programmed to detect different levels of E-cadherin and beta-catenin, aiding in the target identification and drug delivery [15]. Moreover, smartphone-based biosensors are attractive to researchers because they can easily enable both qualitative and quantitative analysis of the sample in real time using a smartphone application that can perform the measurement of colorimetric, fluorescent, reflection-based, current, and turbidity signals[21]. Fluorescence smartphone biosensors were progressed via the condense microscope simultaneously to assure fluorescence labeled diagnostics for viruses, bacteria, DNA, and nanoparticles. Donmez et al., [2020] introduced a smartphone label-free bacterial detection through Light scattering via dark-field imaging. This proposed smartphone biosensor inside the micro-capillary film (MCF) can quantify bacteria without adding dyes or probes by a bacteriophage lysis reader. It included a light source (white LED), MCF test strip (specimen), a camera smartphone (one of the iPhone 6S, or Xperia compact camera S120), and blocker agents (removing the scattered lights in a low angle detection from the detector) [22]. In recent years, the detection methods of biosensors modified by nanomaterials have been continuously mature, and new nanomaterials have been applied more and more in this regard. Biosensors modified with nanomaterials have become an effective means of biomolecules detection, which greatly promotes the development of disease diagnosis technology [23]. ML can effectively process big sensing data for complex matrices or samples. The other benefit of ML in biosensors includes the possibility of obtaining reasonable analytical results from noisy and low-resolution sensing data that may be heavily overlapped with each other. Moreover, proper deployment of ML methods can discover hidden relations between sample parameters and sensing signals through data visualization, and mine interrelations between signals and bioevents. Especially, ML can be used to analyze the raw sensing data from a biosensor in several ways: (1) Categorization: the sensing signals can be sorted into various categories by the algorithms based on the target analyte. (2) Anomaly detection: biosensors are inevitably affected by sample matrix and operating conditions. When biosensors are used on-site, they can significantly interfere with contamination. ML can check the signal and answer the question “does the signal look right?” It can also “correct” sensor performance variations due to biofouling and interferences in real samples. (3) Noise reduction: noise is always included in the sensing signals. The signal from biosensors changes over seconds or minutes, while signal interference such as electrical noise can occur on the



subsecond timeline. Therefore, it is possible to train ML models to distinguish the signal from the noise. (4) Object identification and pattern recognition. By discovering latent objects and patterns using ML algorithms, sensing data can be interpreted easily and effectively. Figure() shows the benefits of ML to biosensors[24].

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Ethical and Safety Concerns

It is well known that AI has the potential to threaten values such as Autonomy, Privacy, and Safety, which are core values in Medicine. Therefore, in order for AI to promote quality of care and minimize potentially disruptive effects, its deployment must take ethics into account [25]. There is no doubt that nanomaterials can be unsafe for use in humans [26]. With the increasing use of nano-materials in all fields of science, including medicine, the question of their safety becomes more and more pressing. They have multiple benefits, but, like a double edged sword, they carry multiple and sometimes unpredictable and serious risk not only for the patient and the producing workers but for the ecosystem in general [27]. Despite the high feasibility for the economy and the environment, there are some considerations regarding the ethical, human dignity and moral borders on nanotechnology that should be taken into account[28].

Future Outlook

Artificial intelligence has impacted immensely on nanotechnology and its applications in medical diagnosis especially in cancer diagnosis and treatment. The future remains bright as more research work is being directed into building more sophisticated, intelligent, independent, and accurate medical systems driven by artificial intelligence with machine learning algorithms to run accurate medical diagnosis. This aims to reduce the rate of human errors and improve on early detection of diseases in human beings through advance image analysis and predictive analysis.

Conclusion

Nanotechnology has influenced many changes in medical diagnosis and has been instrumental in modern attempts to improve medical diagnostic accuracies with efficiency. Despite the many challenges its applications face as a new technology, nanotechnology remains vital to unlocking the potential of advanced medical diagnostics systems to improve healthcare delivery.

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