Artificial Intelligence in Medicine

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ABSTRACT

Artificial intelligence in medicine refers to the use of machine learning models to help process medical data and provide medical professionals with important insights, improving health outcomes and patient experience. Thanks to recent advances in computer science and informatics, artificial intelligence (AI) is rapidly becoming an integral part of modern healthcare. Therefore, artificial intelligence algorithms and other AI-powered applications are now used to support medical professionals in clinical settings and in ongoing research.
There are several applications of Artificial intelligence in medicine, including applications to help detect and diagnose diseases; applications to treat diseases with the help of an AI-powered virtual assistant; AI applications in medical imaging; applications to increase the efficiency of clinical trials; and applications to accelerate drug development. The benefits of Artificial intelligence in medicine can be summarized in providing informed patient care, reducing errors, reducing care costs, and increasing doctor-patient engagement.

1. Introduction

It can be said that emerging computer-based technologies are growing exponentially. Digital healthcare provides many opportunities to reduce human error, improve clinical outcomes, and track data over time. AI methods, including machine learning (ML) and deep learning (DL) algorithms, are widely used in predicting and diagnosing many diseases, especially those whose diagnosis is based on imaging or signal analysis (1) (2). Artificial intelligence can also help identify demographics or environmental areas where diseases or high-risk behaviors are prevalent. For example, facial recognition is also achieved through a process consisting of an encoder and a decoder, where the encoder compresses the input facial image vector x into a lower-dimensional space, while the decoder reconstructs it into its original form (54). Machine learning techniques have also achieved great success in analyzing medical images due to advanced algorithms that enable automated extraction of enhanced features. Machine learning is based on learning methods and can be divided into three categories: supervised (classification, regression, and composition), unsupervised (association, clustering, and dimensions), and reinforced learning (7) (46).

Human intelligence is completely different from artificial intelligence. Human intelligence refers to the sum of many cognitive abilities including abstract reasoning, problem solving, communication, learning, and understanding. Human intelligence also includes many complex emotions that cannot be simulated by a computer, such as love, empathy, happiness, sadness, fear, and embarrassment. Other uniquely human characteristics include common sense, creativity, curiosity, and imagination. Therefore, human decision-making integrates information from all of our senses (36).

Generative Artificial intelligence (GenAI) is a technology that autonomously produces new original outputs based on the large-scale multimodal input data it has been trained on. These include text, images, speech, video, symbols, molecular structures, chemical data, and other types of data (21). GenAI is a subset of the broader Artificial intelligence umbrella that enables computers to learn from the structures and patterns inherent in data, enabling subsequent decision-making (Figure 1) (12).

Deep learning (DL) is a more complex iteration of machine learning (ML), inspired by the architecture of the human brain, using layers of neural networks to assimilate and learn from large amounts of data. Large language models (LLMs) are products of deep learning and have the ability to understand and create texts like human. These LLMs use natural language processing (NLP), a field at the intersection of computer science, artificial intelligence, and linguistics that enables computers to understand, interpret, and generate human language in a meaningful and useful way. GenAI also has applications in the field of computer vision, where generative adversarial networks (GANs) have been implemented to generate many forms of medical images, ranging from pathology slides to ultrasound and MRI (53). Conversely, discriminative AI models (sometimes referred to as predictive models) classify input data, predicting labels based on the information provided (12).

Hence comes the term natural language processing, which includes specific applications of natural language processing such as speech recognition, text analysis, translation, and other language-related purposes. It is used to create, understand, and classify clinical documents and other reported research data. It is useful in analyzing unstructured clinical notes and reporting from these data (41).

As deep learning models scale to large datasets - in part because they can run on specialized computing hardware - they continue to improve with more data, enabling them to outperform many classical machine learning approaches. Deep learning systems can also accept multiple types of data as input - an aspect of particular importance for heterogeneous healthcare data. The most common models are trained using supervised learning, where datasets consist of input data points (e.g., images of skin lesions) and corresponding output data labels (e.g., “benign” or “malignant”) (50). Reinforced learning (RL), where computational agents learn by trial and error or through expert demonstration (18), has advanced with the adoption of deep learning, achieving remarkable achievements. RL can be useful in healthcare when learning requires demonstration by a physician, for example in learning how to suture wounds in robot-assisted surgeries (16)(37). Machine vision, coupled with artificial intelligence, enables robotic systems to interpret images during surgery in real time, ensuring precise navigation, tissue identification, and execution of surgical tasks. Moreover, predictive modeling and decision support systems for personalized surgery play a crucial role in personalized surgery by predicting potential complications and recommending optimal surgical approaches tailored to individual patient characteristics. These models enhance the accuracy of surgical interventions and reduce the risk of adverse outcomes.

Many calculations and operations are performed on the input data through machine learning algorithms. Data preprocessing is the first essential step to reduce false predictions or incorrect results, speed up data processing, and ultimately improve the overall data quality. Then, the data is processed and the crucial features are extracted and implemented according to the specific machine learning or deep learning model for image classification (42).

Machine learning allows computers to perform the tasks of medical professionals and has a widely used subfield in medical image recognition called Deep Learning, which is a method of designing a machine learning algorithm where simple concepts are built on top of each other to form a deep structure with many processing layers. In other words, deep learning is the development of machine learning for analyzing big data. It replaces the classic manual method of designing and extracting patterns used for classification with an automated strategy that allows the computer to identify essential features by training it on a dataset (2). While machine learning is not a new concept, the processing of big data and the increase in computing power have made machine learning successful and popular in recent years.

Deep learning has outperformed previous advanced algorithms in many visual recognition tasks, and its performance has improved dramatically. The ImageNet visual recognition competition is the largest annual object recognition competition. Researchers classified 1.3 million high-resolution images using a deep learning-based CNN model; they significantly improved the model’s performance by achieving error rates of 39.7% and 18.9%, winning the challenge. Deep learning algorithms have become more popular since then. A deep learning algorithm is a deep artificial neural network (ANN) inspired by human brain cells and consists of several simple processing units that combine to form a more complex structure (8). These units are grouped into layers in each algorithm and are referred to as neurons. Input signals are combined and transmitted to other cells if their value is higher than a threshold value. In the artificial type, the signals are replaced by a sum and activation function that combine to create more complex relationships (17), similar to the human brain through a network. The threshold value is a term used in signal processing and image processing. It is a value that represents the minimum signal that needs to be processed. If the signal is less than the threshold value, it is given the value 0 while if the signal is greater than the threshold value, the signal is either taken according to its value or, in most cases, given the value 1.

The convolutional neural network can be defined as a special type of feed forward neural network that derives its inspiration from the biological processes that occur in the optic lobe specifically in the brain of living organisms; is is considered a solution to many computer vision problems in artificial intelligence such as image and video processing (4) (6). It is a successful approach to image analysis and classification and is a supervised deep learning model. It consists of fully connected layers with standard weights that result in fewer parameters for training features through the backpropagation process. It is designed to extract spatial information from input images and aims to learn hierarchical features adaptively, classify image data, and extract their features automatically. The main advantage of this algorithm is to learn highly abstract features with few parameters and simple preprocessing (8). The initialization of the neural network and the order of samples during the training phase are usually random. However, when the training is over, nothing unexpected happens to the neural network.

They involve well-defined computations, but their complex and deep structure often makes them incomprehensible to humans. Therefore, the training method is usually not mentioned in explaining the behavior of networks, and the trained network can be understood usually from the characteristics of the dataset used for training (8).

Researchers use multiple scenarios based on machine learning and deep learning models to predict conditions such as liver diseases, heart diseases, Alzheimer’s, mental illness (47), dentistry, gastroenterology, intensive care (56), and various types of cancers where early detection is vital for treatment (27). Some researchers have also used deep learning techniques to diagnose and identify bacterial pneumonia using chest X-rays for children (4). Significant efforts have been made to identify different features of chest CT scan characteristics for different diseases, and new hybrid models based on case-based reasoning have been proposed to diagnose different skin diseases in different studies (20). The proposal of real-time personal monitoring systems based on artificial neural network techniques is widely used in healthcare to receive vital information about the body; this device can help patients manage their health, especially in critical cases, as researchers have applied artificial neural network models to predict diabetes and achieved 91% accuracy.

Artificial intelligence methods go hand in hand with the Internet of Things (IoT) in the healthcare system in treatment procedures and healthcare technology (13)(48). A reliable IoT-based system using machine learning algorithms for healthcare is proposed to monitor human activities and the surrounding environment through a body sensor network (5). Studies proposed a hybrid IoT model using healthcare monitoring system and random forest technique to predict type 2 diabetes (55) (4).

Thus, edge computing emerged, which is a key technology for processing and analyzing massive amounts of IoT data, requiring decision-making to offload computational tasks to edge servers. Currently, deep reinforced learning (DRL) has been used to solve a number of difficult sequential decision problems by combining reinforced learning (RL) and deep learning (DL) (61).

Researchers have also achieved impressive results in mitigating the risk of type 2 diabetes among people based on their personal lifestyle information and achieved high accuracy using a random forest classifier, which outperformed other algorithms. A mobile-based platform has been developed to detect tuberculosis antibodies in real time using a random forest classifier and achieved an accuracy of 98.4%. A research study proposed an AI-based framework to classify multiple gastrointestinal (GI) diseases, colon cancer, and rectal cancer (58) using recurrent neural networks (RNNs), which are recurrent neural networks or feedback neural networks (RNNs), which are in contrast to feedforward networks (1). The most important feature of RNNs is that the connections between neurons are in one layer and the neurons in the same or previous layer. This is the best way to connect neural networks, especially in the neocortex (8). In artificial neural networks, the recurrent association of typical neurons is used to discover time-coded information in data. Examples of these recurrent neural networks include the Hopfield fully connected neural network. As well as the Long short-term memory (LSTM) and achieved an accuracy of 97.057%.

Fully Connected Neural Networks (FCNNS) consist of neurons and model layers, where the inputs of each layer are connected to each neuron in the layer below. The most straightforward way to understand neurons is to think of them as linear regression models, where each neuron uses input data (x), weights (y), and bias (z) to generate an output (y). If the result after the activation function is zero, the neuron in that particular state is removed. The value of the neuron must pass through the activation function. In any other case, the value will be sent to the next layer of the network. Depending on the type of activation function used, the output value changes. For example, the output of a sigmoid activation function will have an S-shaped curve and range between 0 and 1. The Rectified Linear Unit (ReLU) activation function is another example; for values greater than 0, it has a linear shape, while for values less than or equal to 0, it has a 0 (59).

The global healthcare AI market is expected to reach nearly $188 billion by 2030. This growth comes at a critical juncture in healthcare, with an expected shortage of nearly 10 million doctors, nurses, and midwives worldwide by 2030, at the same time as we face the growing needs of an aging population (32). AI offers practical solutions that can help organizations worldwide overcome these challenges, improve outcomes, enhance care, and promote health equity. However, the potential of generative AI in healthcare, estimated to be worth $17 billion by 2032, is still hard to ignore, with most of it related to medical imaging and drug discovery (9).

Arguably, the most common roles of Artificial intelligence in medical settings are clinical decision support and imaging analysis. Clinical decision support tools can help providers make decisions about treatments, medications, mental health, and other patient needs (4) by providing them with quick access to information or research relevant to their patients. In medical imaging (3), AI tools are used to analyze CT scans, X-rays, MRIs, and other images for lesions or other findings that a human radiologist might miss (4).

Controlling and hypertensive patients and educating them about healthcare are the two most important points to reduce stroke and cardiovascular diseases (5). Researchers have evaluated digital healthcare technologies and artificial intelligence in this regard and proposed a privacy protection system to collect and store individuals' data (9). Moreover, many researchers have conducted studies on disease prediction to identify and predict diseases in their early stages; a new hybrid machine learning model based on the Internet of Things was proposed to detect diseases in the early stages with an accuracy of 100% and 99.50%. Researchers also proposed an approach to predict cardiovascular diseases according to different characteristics. The challenges created by the COVID-19 pandemic for many healthcare systems have led many healthcare organizations around the world to start field test new technologies supported by artificial intelligence, such as algorithms designed to help monitor patients and AI-powered tools to screen COVID-19 patients (1) (4). Hence, it can be asserted that there is no doubt that artificial intelligence will become an essential part of digital health systems that shape and support modern medicine (28).

An important question is whether there is gender or racial bias in the images produced by Artificial intelligence programs such as ChatGPT. It can be said that many AI models generate images based on the data they were trained on. This data reflects the diversity and biases present in cultural content and the broader internet (38), which brings forth another important question on the gender and racial stereotypes that AI programs amplify.

Artificial intelligence models like DALL¢E can unintentionally amplify gender and racial stereotypes present in the data they are trained on. These stereotypes are reflections of societal biases and historical representations in media, literature, and online content. The following are some examples of stereotypes that can be amplified (18):

• Occupational stereotypes: Some occupations may be portrayed as male- or female-dominated. For example, technical roles may be portrayed as male characters, while caring or nurturing roles may feature primarily women.

• Racial stereotypes: Certain racial groups may be overrepresented in specific contexts, reinforcing narrow or stereotypical portrayals. For example, racial diversity may be underrepresented in professional or heroic roles (9).

• Cultural representation: Depictions of cultural elements may tend toward stereotypes, such as clothes or traditional roles, without reflecting the true diversity and modern aspects of those cultures.

• Physical appearance: Stereotypes related to beauty standards, body types, and physical attributes can be reinforced, such as the portrayal of idealized or exaggerated features based on gender or race.

• Activities and roles: The model may associate certain activities or roles with certain genders or ethnic groups, such as sports, hobbies, or household chores, based on stereotypes in the media (9).

The Effective Role of Artificial Intelligence Technologies in Identifying and Predicting Human Disorders and Diseases

Learning algorithms and big data derived from medical records or devices are the most vital tools to efficiently implement Artificial intelligence methods in the healthcare system to improve disease diagnosis and classification, decision-making activities, performance of walking aids, provide optimal treatment options, and ultimately help people have safe and long lives (1) (5). AI is used to improve medical analysis and diagnosis in a short time. For example, this technology can detect dangerous tumors in medical images (4), allowing pathologists to diagnose and treat the disease at an early stage instead of sending tissue samples or lesions to the laboratory for long-term investigation (4). AI-based algorithms are also an effective tool for identifying undiagnosed or underdiagnosed patients and uncoded and rare diseases (23).

In the field of surgical preparation, GenAI could revolutionize organ transplant procedures by facilitating the creation of 3D visualization models from 2D images, thereby improving the accuracy and efficiency of surgical planning for organ transplantation (12). GenAI can also improve education for transplant providers, from physicians to nurses and surgery coordinators, by creating personalized educational materials that target learners' levels, training backgrounds, and different knowledge gaps. Additionally, GenAI's ability to create realistic simulations holds promise for complex surgical training in organ transplantation (12).

There are three major barriers to deploying generative Artificial intelligence in the clinical field today: concerns about inaccurate data, transparency of AI models, and regulation of medical data integrity (18). In addition to ensuring transparency, interpretability, and clarity, AI must be understandable to developers, users, and regulators. Achieving transparency requires providing sufficient information, which must be documented or made available before designing and implementing AI technology. This commitment to transparency not only enhances the overall quality of the system, but also serves as a preventive measure for patient safety and public health. For example, system evaluators rely on transparency to identify and correct errors, and government regulators rely on it to provide effective oversight (34).

Challenges, potential solutions, and future prospects of AI methods

Artificial intelligence plays a broad role in healthcare systems for diagnosis, prediction, and prevention purposes. However, there are several challenges in using deep learning and machine learning techniques in disease diagnosis and prediction. One significant challenge in AI algorithms is the need for massive data in the training phases, which is not always practical for most diseases. Another challenge is data labeling, which requires expertise, is time-consuming, and is very expensive. This can make it difficult to develop accurate models for rare or new diseases. One potential solution to the lack of labeled data is to use techniques such as data augmentation, which can be used to artificially increase the size of a dataset (19).

The computational and architectural complexity of deep learning-based models is another challenge in this field. One potential solution to reduce the computational and architectural complexity of deep learning models is to use model compression techniques such as pruning, quantization, and low-rank factorization. These techniques can help reduce the required number of parameters and computational resources while maintaining good performance. Analyzing low-contrast images is also a challenging task for examining patterns and features (22). Histogram equalization is a technique used in digital image processing, where the image contrast is modified and its histogram is made as flat and distributed as possible. One of the enhancement techniques used to enhance the contrast is to propose a supervised method by machine learning based on the selection of hyperparameters through HE technology to improve the visual appearance and increase the image contrast while maintaining its natural aspect (6). Other researchers have also proposed a new approach to enhance contrast based on HE in cancer diagnosis using medical ultrasound imaging. Medical image compression technology is also used to reduce the transmission bandwidth requirements and storage size (43). Moreover, ultrasound ECG images based on XGBoost algorithm enhancement have been adopted for screening and diagnosis of hypertensive patients during pregnancy in this field. The results found that XGBoost algorithm can obtain clearer and more accurate ECG images and data for patients quickly and effectively compared with normal healthy pregnant women (60).

Artificial Intelligence Applications in Medicine

The future of "standard" medical practice may be closer than anticipated, where a patient might see a computer before seeing a doctor. With advancements in artificial intelligence, it seems possible that the days of misdiagnosis and treating symptoms rather than the underlying cause could soon be gone. While some algorithms can rival doctors and sometimes outperform them in a variety of tasks, they have not yet been fully integrated into daily medical practice because although these algorithms can significantly impact medicine and enhance the power of medical interventions, there are many regulatory concerns that need to be addressed first.

What makes an algorithm intelligent?

Similar to the way doctors learn through years of medical study, performing duties and practical tests, obtaining grades, and learning from mistakes, AI algorithms must also learn how to perform their tasks. In general, they can perform tasks that require human intelligence to complete, such as pattern and speech recognition, image analysis, and decision-making (5). However, humans still need to explicitly tell the computer what exactly to look for in the image provided to the algorithm, for example. Thus, AI algorithms are great for automating tedious tasks, and can sometimes outperform humans in tasks they have been trained to perform (4) (10).

In order to create an effective Artificial intelligence algorithm, computer systems are first fed with data that is usually structured, meaning that each data point has a label or comment that the algorithm can recognize. The algorithm is exposed to sufficient sets of data points and their labels, and performance is analyzed to ensure accuracy, much like students are given tests.

There are many different algorithms that can learn from data. Most AI applications in medicine read some type of data: numerical (such as heart rate or blood pressure) (5) or image-based (such as MRI scans or images of biopsy tissue samples) as input. The algorithms then learn from the data and produce either a probability or a classification. For example, an actionable outcome might be the probability of an arterial clot given heart rate and blood pressure data, or the classification of an imaged tissue sample as cancerous or non-cancerous (29). In medical applications, the algorithm's performance on a diagnostic task is compared to that of a physician to determine its ability and value in the clinic (27).

Advances in computational power coupled with the massive amounts of data generated in healthcare systems make many clinical problems ready for AI applications. There are two recent applications of accurate, clinically relevant algorithms that could benefit both patients and clinicians by making diagnoses clearer. The first is one of several existing examples of an algorithm outperforming doctors on image classification tasks. In the fall of 2018, researchers at Seoul National University Hospital and College of Medicine developed an AI algorithm called DLAD (deep learning based automatic detection) to analyze chest X-ray images and detect abnormal cell growth, such as potential cancers. The algorithm's performance was compared to the detection abilities of several doctors on the same images and outperformed 17 of 18 doctors. It also detected several diseases such as lung nodules/masses, pneumothorax, pulmonary tuberculosis (39), thyroid cancer (57), and bone fractures (44).

The second algorithm comes from researchers at Google Artificial Intelligence Healthcare, also in the fall of 2018, who created the YmphNode Assistant (LYNA) algorithm, which analyzes tissue slides (stained tissue samples) to identify metastatic breast cancer tumors from lymph node biopsies (3) (4). This isn't the first application of AI to attempt tissue analysis, but it's interesting that this algorithm can identify suspicious areas that are indistinguishable to the human eye in submitted biopsy samples.

Recently, other imaging-based algorithms have shown similar potential to boost physician accuracy. In the short term, doctors could use these algorithms to help double-check their diagnoses and interpret patient data faster without sacrificing accuracy (4). But in the long term, government-approved algorithms could operate autonomously in clinics, allowing doctors to focus on cases that computers can't solve. LYNA and DLAD are prime examples of algorithms that complement doctors' classifications of healthy and diseased specimens by highlighting salient features of images that should be studied more closely. These works illustrate the potential strengths of algorithms in medicine.

Regulatory implications and limits of algorithms in the future

So far, algorithms in medicine have shown many potential benefits for both doctors and patients. However, regulating these algorithms is a difficult task. The US Food and Drug Administration has approved some assistive algorithms, but there are currently no universal approval guidelines. Moreover, the people who create algorithms for use in the clinic are not always the doctors' treating patients; thus, in some cases, computational scientists may need to know more about medicine while doctors may need to know which tasks a particular algorithm is or is not suitable for. While AI can assist with diagnosis and basic clinical tasks, it is difficult to imagine automated brain surgeries, for example, where doctors sometimes have to change their approach on the spot once they see a patient. In these and other ways, the capabilities of AI in medicine currently outpace those of AI for patient care. However, clear guidance from the FDA could help define requirements for algorithms and could lead to an increase in the number of algorithms used clinically (18).

Furthermore, the FDA imposes strict standards for approval of clinical trials, requiring extreme transparency around scientific methods. Many algorithms rely on extremely complex and difficult-to-untangle mathematics, sometimes called "black boxes," to get from input data to final results. Perhaps, the inability to "black box" an algorithm and explain its inner workings affects the likelihood of FDA approval of an AI trial. Understandably, researchers, companies, and entrepreneurs may be reluctant to disclose their proprietary methods to the public, at the risk of losing money by having their ideas taken and implemented by others. If patent laws were to change from their current state, where an algorithm can technically only be patented if it is part of a physical machine, the mystery surrounding the algorithm's details might diminish. In either case, greater transparency in the near term is necessary to prevent patient data from being mishandled or mislabeled (4)(5), and thus it might be easier to determine whether an algorithm will be accurate enough in the clinic.

Hence, it can be argued that a correct understanding of the limitations of algorithms by clinicians and a correct understanding of clinical data by programmers is the essential key to creating algorithms that can be used in the clinic. It may be necessary for companies to sacrifice the secrecy of their algorithms' functionality so that a broader audience can examine the methods and point out sources of error that could ultimately affect patient care. Thus, it seems that we are still far from algorithms that operate autonomously in the clinic, especially in the absence of a clear path to clinical approval.

Companies like Google, Enlitic, and many other startups are developing algorithms to interpret AI-derived images. Jvion offers a “clinical success machine” that identifies patients at high risk as well as those most likely to respond to treatment protocols. Each of these machines could provide decision support to doctors seeking to find the best diagnosis and treatment for patients. There are also several companies focusing specifically on making diagnosis and treatment recommendations for certain cancers based on their genetic profiles (11).

How to use artificial intelligence in medicine:

1. **Artificial Intelligence in Disease Detection and Diagnosis**

Unlike humans, AI never needs to sleep. Therefore, machine learning models can be used to monitor the vital signs of critically ill patients and alert doctors if certain risk factors increase. While medical devices such as heart monitors can track vital signs (5), AI can collect data from those devices and look for more complex conditions, such as sepsis (sepsis is a potentially life-threatening condition caused by the body destroying its own tissues in response to an infection. When the body’s infection-fighting processes go awry, it can cause organs to stop functioning properly.) An IBM client has developed a predictive AI model for premature babies that is 75% accurate at detecting severe sepsis. Preterm birth is the birth of a baby at less than 37 weeks of gestation. These babies are known as premature babies.

Accurate diagnosis of diseases is crucial for treatment planning and ensuring patient’s well-being. However, human errors limit the accuracy and efficiency of diagnosis (4), especially in general clinical practice and rural areas, where interpreting medical knowledge is a complex and cognitively challenging task. AI techniques, such as convolutional neural networks (30), knowledge graphs, and transformers, have been validated as powerful and promising tools to help improve the diagnosis and even treatment of various diseases (14). Therefore, the application of AI within the diagnostic process supports medical professionals to improve the accuracy and efficiency of diagnosis and provide emerging digital healthcare services.

2. **Treating diseases with the help of an AI-powered virtual assistant**

Precision medicine could be made easier with the help of virtual AI. Because AI models can learn and retain preferences, AI has the potential to make personalized recommendations in real time to patients around the clock (4). Thus, a new term has emerged: precision medicine or personalized medicine. That’s because even the world’s best scientists and doctors don’t yet fully understand how different people get sick and respond to treatments. The result is a “one-size-fits-all” approach to medicine that relies on broad population averages. This traditional practice often fails because each person’s genetic makeup is slightly different from everyone else’s (21). The advent of precision medicine is bringing us closer to more accurate, predictable, powerful, and personalized healthcare for the individual patient. Our growing understanding of genetics and genomics - and how they drive health, disease, and drug responses in each person - enables doctors to provide better disease prevention, more accurate diagnoses, safer drug prescriptions, and more effective treatments for many diseases and conditions. Tailoring health care to each person's unique genetic makeup is the promising idea behind precision medicine, also known as individualized medicine, personalized medicine, or genomic medicine (4).

Historically, the practice of medicine has been largely reactive. Even today, we typically have to wait for diseases to appear and then try to treat them. Because we do not fully understand the genetic and environmental factors that cause serious diseases such as cancer, Alzheimer’s, and diabetes (4) (49), technology increasingly allows health care providers to shift the focus of medicine from reactive to preventive; predict disease susceptibility (4); improve disease detection; anticipate disease progression; personalize disease prevention strategies; prescribe more effective medications; avoid prescribing medications with predictable side effects; reduce the time, cost, and failure rate of clinical drug trials

(4); and eliminate the inefficient trial and error that inflates health care costs and undermines patient care.

Interactions between hundreds of genes and gene networks, along with external factors such as diet and exercise, determine our biological traits like hair color, eye color (4), cholesterol levels, and our health status. Systems genetics constitutes a comprehensive approach to studying and understanding this biological complexity (21).

3. Artificial Intelligence in Medical Imaging

The application of AI is one of the most promising areas in health innovation, especially in medical imaging such as magnetic resonance imaging and computed tomography (4), where it could contribute to predicting the diagnosis of cancerous lesions in oncology patients using texture analysis and other advanced methods (20); predicting the treatment response to oncology-specific therapies, such as intra-arterial therapy for hepatocellular carcinoma; assessing the biological significance of borderline cases diagnosed in pathology through needle biopsy of mammography findings (4); estimating functional parameters, such as fractional flow reserve from coronary angiography using deep learning; detecting perfusion and ischemia defects (5), for example in the case of perfusion defects resulting from myocardial stress and induced ischemia; and segmentation and morphological modeling, such as brain tumor segmentation or, more generally, brain structure segmentation (35).

4. Clinical Trial Efficiency

A lot of time is spent assigning medical codes to patient outcomes and updating relevant datasets during clinical trials. AI can help speed up this process by providing faster, smarter medical code searches. Two IBM Watson Health customers recently discovered that they could reduce the number of medical code searches by more than 70%. Clinical trials are a critical tool for creating new knowledge about how to help patients heal. Nevertheless, despite the efforts to accelerate this work, clinical trials remain inefficient, expensive, slow, and unequal. There are several reasons behind the complexity of clinical trials, which including:

• To ensure that trials focus on benefiting specific diseases and/or groups of patients, detailed “inclusion” and “exclusion” criteria are developed. This means that only a small proportion of patients with a disease are eligible to enroll in a research study. For example, a study of a new chemotherapy treatment for breast cancer might exclude patients with hypertension, diabetes, or allergies and might also set limits on the age of eligible patients or the type of breast cancer (26).

• There are many regulations and multiple bodies that provide oversight of experiments, which can lead to an enormous amount of administrative burden.

• The end result of these and other imbalances is that it takes more money and time to study and approve new drugs and devices to help our patients. This is a major reason that the average cost of developing a new drug can be close to a billion dollars.

5. Accelerating Drug Development

Drug discovery is often one of the longest and most expensive phases of drug development. AI can help reduce the cost of developing new drugs in two primary ways: by creating better drug designs and finding promising new drug combinations. With AI, many of the big data challenges facing the life sciences industry can be overcome. The biopharma industry is on the verge of a revolution, with AI emerging as a transformative force in drug development. AI’s ability to reduce the time and cost of bringing new drugs to market is not just a promise; it’s a reality. It can reshape drug development, analyzing the mechanisms behind each approach and its future potential and ranking them by their overall impact on the industry.

Drug formulation, a critical step in drug development, involves determining the appropriate chemical structure and composition of a new drug. AI algorithms can predict the solubility and stability of solutions, facilitating more efficient drug formulation (2). An example is the AI-powered Schrödinger platform, which uses predictive modeling to optimize the molecular structure of drugs. AI is expected to begin incorporating more advanced simulation techniques (7), such as quantum computing (an interdisciplinary field that includes aspects of computer science, physics, and mathematics and uses quantum mechanics to solve complex problems more quickly than conventional computers), to predict molecular behavior more accurately. This advance will reduce the time required to formulate drugs. Despite its importance, this aspect ranks third in terms of overall impact. Optimizing drug formulation is more about improving existing processes than revolutionizing them, but it significantly reduces development timelines.

6. Informed Patient Care

Integrating medical AI into physician workflows can give providers valuable context as they make care decisions. A trained machine learning algorithm can help reduce research time by giving physicians valuable research results with evidence-based insights into treatments and procedures while the patient is still in the treatment room (11). By streamlining healthcare workflows through incorporating AI as part of diagnostic services, healthcare organizations facilitate faster diagnoses and treatment decisions, improving patient outcomes (4).

Sophisticated AI algorithms support radiologists, who read hundreds of medical images every day, helping them analyze images such as X-rays and MRIs faster and more accurately (51). This allows care teams to prioritize complex and urgent cases and detect cases that may require additional testing. It also alleviates staff burnout and supports staffing needs. In fact, time-consuming but necessary administrative tasks overburden staff and keep doctors away from the patient's bedside. New AI tools can help alleviate burnout and free staff to focus on patients by automating manual and repetitive tasks such as entering data into electronic health records and submitting prior authorization applications to insurance companies (11). In addition to supporting staff in their daily work, AI helps address staffing needs. Historically, hiring nurses has been a highly manual process that relies on phone calls, text messages, and spreadsheets. Today, we increasingly use AI analytics to streamline this process, including pairing team members who have previously collaborated because research shows that it positively impacts productivity (24).

Furthermore, robotic process automation (RPA) performs organized digital tasks for administrative purposes, i.e. those involving information systems, as if they were a human user following a script or rules. Compared to other forms of AI, it is inexpensive, easy to program, and transparent in its actions. RPA does not only involve robots but also computer programs on servers. It relies on a combination of workflow, business rules, and the integration of the "presentation layer" with information systems to act like a semi-intelligent user of systems in healthcare (11) (15).

7. Increasing physician-patient engagement

Many patients think of questions outside of regular working hours. AI can provide round-the-clock support through chatbots that can answer basic questions and provide patients with resources when the healthcare provider's office is closed. AI can also be used to triage questions and flag information for further review, potentially helping alert providers to health changes that require additional attention.

The following are the most important tools used to increase doctor-patient participation and increase effectiveness and partnership:

• Intelligent virtual assistants (chatbots)

Patients reach out to healthcare providers to seek medical help, find the right provider/doctor, schedule appointments, and address various other needs. However, healthcare providers may not have the staff to adequately assist customers with their queries. To ensure ongoing support, healthcare providers can implement AI-powered intelligent virtual assistants (chatbots) to automate responses to patients' simple queries and requests (37).

Patients can interact with these bots through their preferred digital channel and receive quick answers. These bots efficiently manage and resolve patient queries, reduce manual intervention, and gather relevant patient information for appropriate decisions. In cases where virtual conversations require escalation, patients can be seamlessly directed to the most appropriate channel and form of care. This allows healthcare providers to scale their services, especially during high-volume patient consultations. Generative AI, powered by advanced natural language processing, takes the capabilities of AI chatbots to the next level, enabling more nuanced conversations and allowing healthcare organizations to provide personalized and accurate information to patients (4).

• Patient self-service portals

Creating self-service patient portals is pivotal to addressing today's patients who use digital technology and expect healthcare services to be readily available. Historical health records and lab reports, past appointment data, no-show/lateness records, discharge summaries, childhood immunization and vaccination histories (32), and healthcare provider notes (4), enable patients to access relevant information and avail healthcare services from any connected device at any time. By incorporating advanced AI-powered features into these portals, healthcare providers can increase patient engagement, streamline processes, and enhance the overall patient experience. Modern self-service portals offer the user the following features:

- Appointment Alerts: Alerting the patient to the next upcoming appointment.
- Appointment Scheduling: Enabling patients to book, change, or cancel appointments anytime and anywhere.
- Doctor Recommendations: Recommending the most suitable and nearest doctors for patients to consult and automatically offer them a choice of time slots.
- Cost Estimation: Giving patients an estimate of the cost involved in consultations and other medical interventions.
- Payment and Claims Information: Helping patients be prepared with payment information to file claims.
- Personalized Insights: Providing personalized insights into patients' health management by analyzing their health data.

• Comprehensive view of the patient

The healthcare industry is one of the most data-driven industries. Data in healthcare is generated through various channels such as patient registration, electronic medical record systems, physician consultation notes, patient feedback, and patient claims details (5). Integrating patient data from multiple source systems is crucial for healthcare providers to get a holistic view of the patient. AI enables healthcare providers to get this holistic view of patients and provide relevant and timely services to patients through the following:

- Examining large amounts of consolidated patient data to gain insights.
- Tracking a patient's history across all services they have requested and better meet their needs.
- Gaining additional information about patients in terms of improving future patient engagement.
- Using patient feedback to proactively address issues for other patients (5).
- Improve operational efficiency inside the organization.

• Risk assessment for preventive care

AI-powered solutions offer valuable insights to healthcare providers, especially in the early detection of diseases such as cancer, diabetes, and coronary artery disease (4). By analyzing data from various sources, including X-rays and medical images, AI can help identify patterns associated with the onset of such diseases. Furthermore, the integration of AI with smart devices, such as wearable smart bracelets, enables continuous monitoring of patients' heart rates (5). This enables proactive health management and acts as a warning system, alerting doctors, caregivers, or patients about an impending heart attack or stroke and saving lives.

• Improving the healthcare workforce

Patient experience suffers when there are delays and waiting time. By leveraging advanced analytics and AI, providers can manage their resources more efficiently and address this challenge (31). By leveraging these technologies, healthcare professionals can identify specific areas of delay and identify bottlenecks that may be hindering patient satisfaction. With a smart and data-driven solution, staff can efficiently allocate available physicians and deliver timely consultations (4). Additionally, integrating an AI-powered workflow management platform can enable healthcare coordinators to automate workflows and reduce manual interventions. From follow-ups and consultation scheduling to medication dosing advice, these systems can automate patient care processes from end-to-end for a comprehensive transformation of the patient experience (25).

• Automating medical coding and billing processes

Spelling mistakes, abbreviations, and other ambiguities make medical coding time-consuming and resource-intensive. This is where AI-assisted medical coding solutions can be a game-changing asset for healthcare entities, automating medical coding tasks to achieve the highest levels of accuracy and speed. This extraordinary improvement in speed translates into faster reimbursements and reduces financial stress for both providers and patients (11). Fewer mistakes reduce the likelihood of billing disputes, fostering a relationship of transparency and trust between the provider and patients (5). More importantly, improved accuracy and efficiency of medical coding improves health outcomes as physicians can rely on a more complete and reliable understanding of a patient's medical history, past treatments, and ongoing health issues to make informed decisions. This reduces the likelihood of missed treatments and also allows for a more personalized approach to patient care (4).

• Managing Patient No-Shows or delays

Patient no-shows cost the healthcare industry millions of dollars, and duplicate appointment scheduling practices lead to resource wasting, operational inefficiencies, and poor decisions. All of these gaps ultimately impact the patient experience. A web application with AI and data analytics capabilities to streamline various patient management processes such as appointment scheduling, patient registration, and EHR/EMR management can be one of the most important uses of AI in healthcare. For example, modern appointment management systems with predictive analytics capabilities can anticipate patient no-shows or lateness, enabling providers to take proactive measures such as automatically placing patients on a waiting list. This reduces average waiting time, reduces the number of missed appointments, and ensures a smoother, more patient-centered care experience (11).

• Automated Summarization of Physician Notes

Another interesting use for AI in healthcare is in mental and behavioral health, where healthcare practices often face the challenge of manually summarizing large volumes of physician notes that flow into their EMR system (3). This challenge can be addressed with a transformative AI model that can be easily integrated into the EMR system. The AI model can adeptly assimilate and process large volumes of detailed physician-patient conversations from their question-and-answer sessions and automatically generate clear and comprehensive summaries of the conversations in real time (52). This improved efficiency and effectiveness of physician note summarization extends beyond administrative efficiency and becomes a critical step in enabling providers to quickly extract key information from voluminous notes and accelerate decision-making. Additionally, healthcare professionals can detect patterns, track progress, and proactively assess potential mental health concerns (4), thereby improving the quality of patient care and experience.

Ethical Implications

Finally, there are also a variety of ethical implications about the use of AI in health care. Health care decisions were made almost exclusively by humans in the past, and using intelligent machines to make or assist in those decisions raises issues of accountability, transparency, consent, and privacy (18). Transparency is perhaps the most difficult issue to address with today's technologies. Many AI algorithms, particularly deep learning algorithms used to analyze images, are nearly impossible to interpret or explain. If a patient is told that an image has led to a cancer diagnosis, they will likely want to know why, and deep learning algorithms, even doctors who are generally familiar with their operation, may not be able to provide an explanation (11).

Justice in medical ethics emphasizes the equitable distribution of health care resources, treatments, and opportunities, addressing disparities and ensuring universal access. Integrity and confidentiality highlight the importance of honest and transparent communication while protecting patient privacy (34).

Professional fidelity emphasizes the commitment of health care professionals to fulfill their duties and obligations and to maintain trust through the doctor-patient relationship and the broader health care system. Together, these principles form the ethical compass that guides decision-making in medicine, ensuring a balance between individual rights, societal equality, and the integrity of the medical profession (40).

AI systems will undoubtedly make mistakes in diagnosing and treating patients, and accountability for these mistakes may be difficult to establish. Incidents are also likely to occur in which patients receive medical information from AI systems that they would rather receive from a human doctor. Machine learning systems in healthcare may also be subject to algorithmic bias, perhaps predicting a higher likelihood of disease based on gender or race when these factors are not actually causal (11).

We are likely to face many ethical, medical, professional, and technological changes with AI in healthcare. It is important that healthcare organizations and government and regulatory bodies establish structures to monitor key issues, respond responsibly, and establish governance mechanisms to mitigate negative impacts. This is one of the most powerful and impactful technologies on human societies, which requires continued attention and thoughtful policy for many years.

The biggest challenge for AI in these healthcare settings is not whether the technologies will be powerful enough to be useful, but ensuring that they are adopted into everyday clinical practice. For these systems to be widely adopted, they need to be approved by regulators, integrated into electronic health records systems, standardized enough that similar products work the same way, taught to clinicians, paid for by public or private organizations, and updated over time in the field. These challenges will eventually be overcome, but it will take much longer than it took for the technologies themselves to mature. As a result, we expect to see limited use of AI in clinical practice within 5 years and more widespread use within 10 years.

It is increasingly clear that AI systems cannot replace human doctors on a large scale, but rather augment their efforts to care for patients. Over time, human doctors may move toward tasks and job designs that rely on uniquely human skills such as empathy, persuasion, and holistic integration. The only health care providers who may lose their jobs over time may be those who refuse to work alongside AI.

Medical Data Integrity

Since GenAI relies on large and extensive datasets often derived from electronic health records, there is an inherent risk of inadvertent disclosure/breach. PHI must be protected at all costs and cannot be loosely used or combined with publicly available LLMs. In fact, many healthcare organizations have now started using PHI-compatible versions of GPT and LLaMA for clinical integration of GenAI tools. Although patient data de-identification is practiced, challenges remain in ensuring that personally identifiable information is completely removed. Finding a balance between the usefulness of the data for model training and maintaining patient privacy requires strong encryption methods, secure storage protocols, and adherence to strict regulatory frameworks such as the Health Insurance Portability and Accountability Act (HIPAA) (12).

As for the ethical and disciplinary aspects of AI in healthcare, four main groups of ethical and disciplinary conflicts can be distinguished: confidentiality and data protection, safety, responsibility (34), and impact on the doctor-patient relationship. Regarding confidentiality and data protection, the use of AI and machine learning in medicine requires access to large health databases. A crucial ethical issue concerns the access to and use of this data, particularly with regard to privacy, confidentiality, and secrecy. The European Union has promoted a pioneering law on AI, known as the AI Act, which includes references to the collection and processing of health data, with consent at its core. Patients must know and expressly agree to the use of their correct data. In addition, strategies for controlling access, anonymizing patient data, and protecting patient data are essential to ensure the ethical use of patient data. Patient data will also be regulated in another draft, and there is already a proposal for the regulation of the European Health Data Space (EHDS) (15).

This project aims to create health data (for primary use) in all Member States, both for primary and secondary uses, such as research and innovation, by promoting interoperability. Some analyses of this proposal consider that more attention should be paid to privacy and data protection issues, especially with regard to the provisions for voluntary subscription to healthcare applications. The EHDS would also enable interoperability between wellness and lifestyle devices (such as smartwatches or IoT devices) with computerized health records through a self-proclaimed labeling scheme. This regulation has a potential impact on the market, where large technology companies, such as Amazon, Google or Apple, have entered.

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