# Artificial Intelligence in Medicine

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# Artificial Intelligence in Medicine

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**Abstract**
Artificial Intelligence (AI) is the technology related to simulating human behaviour in machines. Machine intelligence is a subfield of AI in which available raw data is processed to learn inherent patterns and build a model to adapt to new data. Deep learning models utilize very large amount of data and extract important features and classify the data. Multiagent systems or distributed AI systems are autonomous, proactive, reactive and have ability to interact with humans and other agents. Medicine includes all the processes involved in preventing, diagnosing and curing diseases. It includes medical staff and supporting staff records, drug information, decision support information for medical professionals, clinical lab tests, X-rays, magnetic resonance images, surgeries, and so on. AI has a number of applications in medicine including expert systems, medical robots, medial image analysis and distributed medical agents etc. Expert systems can function as medical experts and helpful for patients who are unable to reach a medical specialist due to cost, or being in a remote area. The role of AI is significant in radiology as abnormal data is labelled in medical images obtained from computed tomography, X-rays, and magnetic resonance imaging etc. more accurately. Medical robots assist in patient care, clinical settings, surgeries and in many other ways. Distributed medical agents enable the availability of a number of medical experts online to examine critical cases. In this paper the role of artificial intelligence in the above mentioned medical applications is elaborated with relevant examples. It is concluded that AI is indispensable in medicine for effective and efficient healthcare.

**Keywords**: Artificial intelligence, Machine intelligence, Deep learning, Medical image analysis, Robotic surgery, Distributed medical agents

## Introduction

Computers were traditionally used for applications involving high-speed computations, and storage and retrieval purpose. Medicine includes all the processes involved in preventing, diagnosing and curing diseases. Traditional applications of computers in medicine include hospital administration with information systems for patients, doctors, paramedical staff, and drugs and clinical data. In medical imaging, computers were used for measurement, interpretation, reporting, filtering and retrieval of data with limited capabilities for decision support. Telemedicine allows telecommunication between doctors and patients or other doctors using Internet. Public health organizations like world health organization (WHO) and the centres for disease control have prepared huge databases of information related to diseases and health statistics. Computer networks and the Internet have increased the means of communication between medical professionals via emails, video chats and webinars. Electronic health record is the digital version of a patient's health record that is instantly available to authorized health providers and provides health history of the patient. Computer based patient monitoring machines allow heart rate, respiratory activity, blood pressure and other vital parameters to be collected automatically in digital form and notify unusual changes to patient's critical parameters. Super computers and distributed computers are able to handle large amount of research data and analyse millions of records. The mapping of the human genome is an example of advancement in medical research due to computers. Computers are used to assist in pre-surgical planning and performing many surgical procedures.

Artificial Intelligence (AI) is the part of computer Science concerned with the design of computer systems that exhibit the attributes of human intelligence. Some attributes of human intelligence include memory retention and recall, exhibiting Common sense, learning from experience, perceiving through senses, Creativity – creating something new and useful, and decision making. Artificial Intelligence has the potential to automate many tasks that require human intervention and hence plays important role in many disciplines including health. Intelligent applications process large amount of information to extract inherent knowledge. Medical applications involve large data sets and hence AI has number of applications in medicine. AI technique is characterized by search, use of knowledge and abstraction. Search is a very important process in the solution of hard problems for which no more direct techniques are available. Knowledge provides a way of solving complex problems by exploiting the structure of the objects that are involved. Abstraction provides a way of separating important features and variations from many unimportant ones. Intelligent systems are open ended, complex, dynamic, uncertain and manipulate symbols. Knowledge is indispensable in AI because knowledge is provided by people who understand it and it can be used in many situations.

**Computer applications in medicine:** Computer information systems have been used in hospitals for improving the overall management and service level of the hospital. Human resource management, medical care management, computer-based patient record, storing, retrieval and sharing of medical resources in digital form were some of the important computer applications in hospitals. Computers were used in medical imaging for various processes including preprocessing, analysis of complex images and to compress large images. Medical instruments and computer technology together were used for measurements and calculations, automatic data processing, and real time control [1, 2]. E-health is a developing research field that includes applying digital modes such as computers and smartphones and involves various forms of latest communication media into healthcare. Telemedicine is a part of E-health. Telemedicine or Telehealth, E-health, and MAS play a significant role in creating efficient patient-oriented care for chronic pain management [3].

**Types of Intelligence in Machines**: Artificial Intelligence (AI) is the technology related to simulating human behaviour in machines. Machine Learning (ML) is a subfield of AI in which available raw data is processed to learn inherent patterns and to build a model to adapt to new data. Deep Learning (DL) is a type of machine learning that uses artificial neural networks with multiple layers of processing and extracts higher level features from very large amount of data. Multiagent systems (MAS) or distributed AI systems are autonomous, proactive, reactive and have the ability to interact with humans and other systems.

**Artificial Intelligence, Machine Learning, and Deep Learning:** Though AI and ML are sometimes used interchangeably ML is a subset of AI. Applications of AI include expert systems, robotics, natural language processing, machine vision, and speech recognition. Artificial intelligence programs are developed based on relationships, procedures, and decision logic with rules. Machine learning algorithms iteratively learn from problem specific training data and improve performance over time. An Artificial Neural Network (ANN) is modeled after the massively parallel structure of the brain. ANN simulates a highly interconnected parallel computational structure with many processing elements called neurons. Connection between neurons has a weight that is continuously adjusted during the learning process. Neurons are organized into network with input layer that receives input data, zero or more hidden layers responsible for learning a nonlinear mapping between inputs and output and an output layer that produces final result. Neural networks can learn or they can be trained from examples before solving an unknown instance of the problem. Artificial neural systems can be applied for problems found intractable or difficult for traditional computation and are suitable to solve real-world problems.Supervised machine learning methods build a model by learning from examples representing past experience. Unsupervised machine learning techniques include methods that reveal patterns from input data without any known input-output pairs. In reinforcement learning methods, rewards and penalties allow the model to continuously learn over time. They have been applied successfully in games. Supervised learning uses classification and regression techniques to develop machine learning models. Classification techniques classify the input data and predict discrete responses like the tumour is cancerous or benign**.** Regression techniques predict continuous responses like changes in temperature or fluctuations in electricity demand. Common algorithms for performing classification include support vector machines **(**SVMs**)**, decision trees, k-nearest neighbours, Naive Bayes, discriminant analysis, logistic regression**,** and neural networks**.** Typical applications include medical imaging, speech recognition, and credit scoring. Unsupervised learning is useful for clustering problems, in which the goal is to find the groups of elements that share common properties. Applications for unsupervised learning include gene sequence analysis, and market research. Various types of machine learning algorithms including supervised, unsupervised, and reinforcement learning and their real-world applications in domains such as healthcare, agriculture and E-commerce are explained in [4].

Deep neural networks (DNN) typically consist of more than one hidden layer and neurons that have multiple activations rather than simple activation function as in ANNs. DNN operate on input data and automatically discover a representation with deep learning (DL) for the given task. The decision making of most advanced ML algorithms including deep learning is untraceable and, thus, constitutes a black box. For low-dimensional data Input, with less number of features and limited training data availability, simple ML algorithms can produce superior results and better interpretable than those generated by deep neural networks. DL is very useful for applications with large and high dimensional multimedia data, as deep neural networks outperform simple ML algorithms [5]. Deep learning often produces better results compared to machine learning. DL plays a vital role in building intelligent systems due to automatic feature extraction and improved performance with large amount of data. Deep learning, based on the given data, finds automatically related features and combines them to ease faster learning. The advantage of using DL over other ML algorithms is its capacity to create new features from the set of features already present in the training dataset. DL models include convolution neural networks (CNN), recurrent neural networks (RNN), recursive neural networks, autoencoders, and generative adversarial neural networks (GANs). The architectures vary based on the type of layers, neural units, and connections used. Different categories of DL techniques can perform differently depending on the nature and characteristics of data. The data may be of any form such as sequential, image or tabular. Though the training time is large, the testing time for DL algorithms is very little [6, 7]. The concepts of artificial intelligence, machine learning and their relationship in detail are explained in [8]. Agents, rational agents, artificial intelligence-based information systems architecture with rational agents are also discussed. AI based information systems including adaptive AI systems and machine learning (ML) based AI systems are also elaborated with example systems.

**Intelligent Medical Applications**

**Expert Systems in Medicine:** Expert systems or knowledge-based systems are used to solve problems that are normally solved by human experts. Expert system is a set of programs that manipulate encoded knowledge to solve problems in a specialized domain that normally require human expertise. There are two components in an expert system. 1) Domain knowledge base and 2) Reasoning mechanism or inference Engine. MYCIN [9] is used for diagnosis and treatment of infectious blood diseases, ONCOCIN [10] is an expert system for treatment of cancer patients. and CASNET [11] is for Glaucoma diagnosis. DXplain [12] is an expert system designed to suggest a list of diseases that are associated with a set of clinical findings entered by a medical student or practitioner. CADUCEUS [13] is an expert system developed at the University of Pittsburgh to encompass the diagnostic knowledge of over 700 diseases. A number of expert systems for diagnosis only or for both diagnosis and treatment of problems related to various parts of human body such as ear, neck, shoulder, eye, mouth and foot etc. are included in [14]. The tools used for development of some of the expert systems are also mentioned. An online application in UK known as *Babylon* can be used by the patients to consult the doctor online, check for symptoms, get advice, monitor their health, and order test kits. *Germwatcher* is a system developed by the University of Washington to detect and investigate hospital acquired infections [15] .

**AI in Electronic Health Records (EHR)s Analysis:** EHR contain two types of information. Structured information such as name, age, gender and race, diagnosis, laboratory results, medications, and procedures such as surgery, radiology, and pathology and vital signs as height, weight, pulse rate, and blood pressure. Unstructured information includes clinical notes from physicians, radiology reports, and discharge summaries etc. Recurrent Neural Networks (RNN) can be used to analyze structured data in EHRs. Text analysis techniques in Natural Language Processing (NLP) such as sentiment analysis, automatic text summarization, topic extraction can be used for analyzing the unstructured information in EHRs. AI studies have been conducted using EHRs and algorithms are developed to predict the risk of hypertension, cardiac arrest, and heart failure. Through AI, it would be possible to quickly analyze images and medical data in EHRs to provide appropriate medical services. The interoperability of AI algorithms across different EHRs systems is not only critical but also challenging. EHR data are heterogeneous, sparse, and noisy. Deriving robust AI algorithms that can reliably analyze EHR data is an important task [16, 17]. Different data may provide complementary information of the patient conditions. Performing integrated analysis of physiological signals, and other clinical data will be useful to know the actual condition of the patient. Developing effective computational approaches for such integrated analysis is essential.

**AI in Drug Discovery and development:** Drug discovery and development includes many subfields such as drug design, pharmaceutical product development, quality assurance and quality control, clinical trial design and monitoring, and pharmaceutical product management that includes product costing and product marketing. AI, ML, DL and AI tools are used in all these fields. Their performance with respect to accuracy, consistency and speed outperformed traditional existing techniques. AI techniques also aid in decision making as determining the right therapy for the patient (e.g. personalized medicine) and managing the clinical data generated for future drug development. Many existing techniques were converted to AI based techniques or combined with other existing techniques. Using latest AI based technologies in drug discovery and development, the quality of the products, safety of the production process, efficient utilization of available resources, and cost effectiveness will increase [18].

Data collected in various stages of drug development often contain insights about disease mechanisms and treatments. AI methodologies such as data mining have been used to extract insights from those data. Deep learning models developed based on big data modeling and analysis are useful in safety and efficacy evaluations of drug molecules. AI, ML, and DL algorithms provide solutions to problems in drug design and discovery. The potential for DL algorithms depends on the quality and quantity of datasets [19]. Neural network models and deep learning models were used successfully and showed high performance for chemical toxicity prediction, to predict interactions between drugs and their biological targets and other toxicity evaluations [20]. The prediction accuracy achieved with DL models is more significant compared to traditional ML approaches for 15 absorption, distribution, metabolism, excretion, and toxicity data sets of drug candidates [21]. A number of AI tools are used in drug discovery. For example, DeepChem [18, 22] finds a suitable candidate in drug discovery, DeepTox [18, 23] predicts the toxicity of 12000 drugs, and ORGANIC [18, 24] is useful to create molecules with desired properties.

**Artificial Intelligence in Medical Imaging**

Radiology is a branch of medicine that uses imaging technology to diagnose and treat diseases. One of the typical tasks in radiology practice is detecting structural abnormalities and classifying them into disease categories. Medical imaging technologies include Ultrasonography, Computing Tomography (CT) scans, X-ray Generators, Magnetic Resonance Imaging (MRI) scans, and Positron Emission Tomography (PET) scan etc. They take pictures of the internal organs and tissues of the body from different angles and produce a series of cross-sectional images or three-dimensional detailed anatomical images on the computer very fast. A total body PET scan allows the entire body to be imaged simultaneously. AI in radiology aids in detection of abnormal activity of the body at early stages. As a result, more accurate diagnosis and improved treatment decisions are possible for many diseases including breast cancer, lung cancer and brain disorders. Deep learning algorithms are extensively used in radiology imaging analysis. Various deep learning models showed promising results in detecting and staging the diseases including breast cancer [25], lung cancer [26, 27], and Alzheimer's disease [28, 29, 30].

Machine learning algorithms like logistic regression and support vector machine can suffer from consistency problems due to manual feature selection. As Deep learning works with multiple layers and large data, it automatically extracts important features that can improve performance. For example, using a deep learning model (inception V3) with 127,463 training images and 1,942 testing images, the researchers demonstrated that the model can discriminate between benign and malignant lesions at a level of accuracy similar to that of dermatologists. A dermatologist may review over 200,000 images of skin lesions over decades of work, compared to mere days that it could take for a computer to analyze the same images using AI-assisted techniques. ML approaches have also been used successfully to analyze raw images in cardiovascular imaging studies. There are many challenges like which model to use, availability of data, and type of data used [31].

With the availability of graphical processing units (GPUs) and tensor flow processing units (TPUs), artificial intelligence has the power to process very large number of medical images and can find disease characteristics which could otherwise be escaped by human eye. Though deep learning learns from enormous amount of image examples, the time to process is substantially low as it depends on curated data and the corresponding meta data rather than the domain expertise which might take a number of years to provide. Curated data includes data sets that are created, organized and maintained so that they can be accessed and used by people. Metadata provides information about other data in the form of text or image. However, accurate labelling is a big challenge in data curation [32 ]. Even the best model is deployed, the performance in the real-world situation may degrade over time due to disease prevalence, advances in medical technology and alterations in clinical practice. Continuous monitoring of model performance, and proactive measures to address data set shifts over time can improve the accuracy and reliability of AI models in medical imaging interpretation. Also many AI methods are black boxes in the sense that their decision-making processes are not interpretable by humans. [33].

**Intelligent Robot Applications**

Robotics is a branch of artificial intelligence. Robotic systems can be used inside the body, on the body or outside the body. Those applied inside the body include microrobots, surgical robots or interventional robots. Microrobots are very small devices that can move unimpeded through the body. They can be used for tasks such as targeted therapy or localized delivery of drugs, to assist in physical surgery by drilling through a blood clot, and directed local tissue heating to destroy cancer cells. Robotic prostheses, and orthoses are examples of robotic systems worn on the body. Robotic systems applied outside the body can help to avoid direct contact when treating patients with infectious diseases and assist in remote surgical procedures [34].

**Robotic Surgery:** Robotic surgery (RS) or robot-assisted surgery involves minimally invasive surgery using robots. With developments of new techniques and availability of required facilities, RS enables doctors to perform complex procedures with greater precision and accuracy in many specialties like urology, gynecology, general surgery and neurosurgery. RS is becoming popular because of many benefits like smaller scar, less pain, three-dimensional view of the surgical site, quicker recovery and reduced post operative complications etc. Machine learning techniques learn from surgeon's experience and aid decision-making in real time. A clinical robotic surgical system includes a camera arm and mechanical arms with surgical instruments attached to them. The systems currently in use are not designed to act independently. The three-dimensional view of the surgical field is visible on the console through an endoscopic camera fitted inside the patient's body. The surgeon located at a remote place controls the robot through the console with control devices such as joysticks. The surgical movements produced by the surgeon through the control devices are translated into real time movements by the robotic arms located over the patient. Da Vinci robotic surgical system developed by Intuitive Surgicals approved by United States Food and Drug administration is in use for urological and gynaecological surgeries. The robotic arm of the system mimics a surgeon's hand movements with better precision and has a 3D view and magnification options which allow the surgeon to perform minute incisions. Artificial intelligence uses algorithms that allow machines to perform cognitive functions and hence AI can drive the future of surgical robotics. Robotic systems vary in design and the components are tailored to specific surgical specialties. RS in the emergency setting has not been explored much [35]. The ROBODOC system was the first system used in orthopedic surgery in 1992 for total hip arthroplasty. The CASPAR was another robot used for total knee arthroplasty [36]. In spine surgery, robotic technology has been utilized for spinal fusion and instrumentation procedures [37].

**Distributed Artificial Intelligence in Medicine**

Distributed Artificial Intelligence (DAI) systems or Multiagent systems (MASs) are concerned with intelligent connected systems that interact and decide for themselves what to do to satisfy the design objectives. Agent is a self-contained computer program that can operate robustly in rapidly changing, unpredictable, or open environments. Agent senses input and action output are generated to affect the environment. In multiagent systems several agents coordinate their activities and jointly take action or solve a problem. A global solution arises from the cooperation between these agents, each of them being in charge of a specific subtask, but no one having sufficient resources to produce the global solution. The intelligent agents are often geographically, physically, and logically distributed. For example, treating a patient in a critical condition requires the expert services of many physicians including surgeon, anesthetist, etc. Cooperative decision-making using multiagent systems offer acceptable decisions in many fields including Healthcare, Engineering, Supply Chain Management, and Manufacturing [38]. MAS technology is suitable for healthcare applications as dynamic and distributed data management, use of heterogeneous components and remote collaboration of experts is required in healthcare. In emergency and highly specialized services, joint support of healthcare professionals is essential. The inherent cooperative nature of agents is an important reason for using MAS in healthcare. Also, interaction and communication are central to healthcare and MASs. Various MAS projects for different purposes such as elderly inhouse healthcare, early detection of heart attacks, improving the classification of brain tumours and fast treatment, and allowing non-expert health care practitioners to access specialized knowledge are discussed in [39].

A multiagent system framework is proposed in [40] for chronic, elderly, and distant patients. The framework consists of five agents namely Mobile Agent Doctor Outside Hospital (MADO), Doctor Agent in Hospital (DAH), Specialist Agent (SA), Pharmacy Agent (PA), and Nurse Agent (NA). MADO obtains patient vital signs via the patient's smart device attached to the patient's body. If the vital signs vary from the normal data values, it transmits the signs to DAH via Wi-Fi or through 5G. DAH sends only abnormal cases to SA and SA responds appropriately. PA receives prescription through SA and sends medicines to the patient. NA is responsible for indoor patients sent to the hospital by SA for immediate treatment. The framework was evaluated by using the existing data of four patients and it is concluded that the system was effective.

**Multiagent system for Indian rural child care :** The objective of the system [41] is to provide assistance to the healthcare practitioner working in rural areas for diagnosis of childhood diseases and generation of timely treatment plan so as to reduce the Infant Mortality Rate. The system can alleviate the problems due to non-availability of pediatricians in rural areas. Healthcare practitioner, at rural site, uses a graphical user interface (GUI) of an agent called User Agent (UA) to pass sign-symptoms and to receive treatment plans from a knowledge component called Intelligent Pediatric Agent (IPA) located at an urban area. The IPA communicates with super specialist agent (SSA) [42] located in a city when the child's problem is complex and a specialist needs to be consulted. The functionality of the system includes 1) Designing childhood disease ontology 2) Agent interaction using agent communication language and 3) Designing decision making system using machine learning algorithms. To build an intelligent system, knowledge needs to be captured, processed, reused, and communicated. All these tasks are supported by Ontology. The agent's knowledge is limited to the description of the particular ontology. IPA needs to select one of the five super specialist agents namely: 1.*Endocrinologist* to deals with diseases of endocrinal glands which secrete hormones e.g. Thyroid, Pancreas, and Pituitary etc.2. *Cardiologist* to consult the specialist who deals with diseases due to malfunctioning of heart. 3. *General Surgeon* who treats diseases through surgery. 4. *Pulmonologist* who is required in lung diseases and. 5. *Gastroenterologist* a specialist who is required in intestinal and liver diseases. Based on the problem, one of the SSAs is selected and interacts with IPA and appropriate action is taken.

**Emerging Trends in Artificial Intelligence in Medicine**

**Federated machine learning (FML):** Availability of high quality, high volume of patient data is a constraint due to strict privacy protection rules. Sharing image data from multiple institutions without compromising security is also a big issue. FML is a decentralized approach to machine learning where multiple devices collaborate to train a model without sharing their data with each other or a central server. Thus FML is a distributed machine learning approach that allows collaborative training on decentralized datasets and then, only the trained model parameters are shared. FML trains an algorithm via multiple independent sessions, each using its own dataset. As data transfer is avoided, FML addresses critical issues such as data privacy, data security, data access rights and access to heterogeneous data [33 43].

**Generalist medical AI models:** Generalist medical AI (GMAI) can transform healthcare with its adaptability and comprehensive understanding. GMAI is built through self-supervision on large, diverse datasets and can interpret different combinations of medical modalities, including data from imaging, electronic health records, laboratory results, genomics, and medical text. It is versatile and can adapt to new tasks. Limitations of conventional AI includes human intervention and human error, and need to ensure privacy and security concerns of patient data management. AI models like large language models (LLM) for text data and combined text and image data have brought progress in generalist medical AI models. LLM are AI models consisting of a neural network with billions of weights trained on large amount of unlabeled data. Application of LLM for text-based tasks in medicine include chatbots such as GPT-4 (generative pre-trained transformer-4) that are capable of expert level note-making, question-answering and consultations. A new generation of generalist AI models have the capability to tackle the entire task of a radiologist. The clinical content, the image data and the previous image data are combined in the decision of the model. Studies on such models have shown that they can detect several diseases on images at an expert level. Given a medical image and relevant clinical information, using a single generalist model, future AI models will be able to produce a complete radiologic report for the radiologist, a patient friendly report in the preferred language for the patient, recommendations regarding a surgical approach that are based on best practices for the surgeon, and evidence-based follow-up suggestions and tests for the primary care provider. In addition to this, these models may be able to generalize to new geographic locations, patient populations, disease distributions, and changes in medical technology only with some relevant new data. Validation of such models remain an important area for study. The generalist AI models to provide comprehensive solutions to the task of interpretation of radiologic images is likely to transform both the fields of radiology and healthcare [33, 44].

**Automated Machine Learning (AutoML):** Though the utilization of machine learning techniques improved healthcare with reduced costs, to build an optimal machine learning model is a challenging task for many healthcare professionals. AutoML is an emerging research field with the goal of automatically optimizing parts of machine learning process. AutoML automatically selects model, and finetunes hyperparameters to achieve optimal performance on a given task and/or dataset. Hyperparameters are defined by the user to control the learning process such as learning rate, number of nodes, and number of layers in a neural network. The main limitation of AutoML is the ability to work efficiently on large datasets. Auto-WEKA, Autosklearn and TPOT (tree-based pipeline optimization tool) are the three dominant open-source AutoML pipeline optimizers [45].

## Conclusions and scope for further research

Computers are widely used in medicine for information processing applications. Artificial Intelligence has the potential to automate many tasks that require human intervention. AI with Machine Learning and Deep Learning algorithms plays important role in medical image analysis. It changed the way people process the enormous number of images. Availability of the set of medical images depends on clinical practices. Robot-assisted surgery, allows doctors to perform many types of complex procedures with more precision, flexibility and control. Issues related to security, privacy and ethics play vital role across all aspects of healthcare. Multiagent medical systems solve complex and distributed problems in a cooperative way. Multiagent systems are ideal to support e-health services and applications.

To organize the data generated from different medical practices in a standard way is a big challenge in AI based medical imaging research. Standards are required in sharing patient data across institutions without compromising security and under strict privacy protection rules. Data organization, data curation, accurate labelling, efficiency and accuracy in processing are still challenges in medical imaging. Development of fully autonomous robots without human intervention is a big challenge due to the requirement of powerful algorithms and ethical regulations. In multiagent systems, issues such as lack of centralized control, legal and ethical issues in the exchange of patient information between agents are to be resolved.

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