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Use of Artificial Intelligence for Improving Patient Flow and Healthcare Delivery

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Abstract

Artificial Intelligence (AI) is as a promising tool for supporting the healthcare administration and it is fundamentally changing medicine. AI mainly refers to doctors and hospitals analyzing vast data sets of potentially life-saving information through AI algorithms. These algorithms have several applications in hospitals, clinical laboratories, and research facilities. In this review, we will provide an overview of applications of AI in improving patient flow to the hospital and patient transfer within a hospital.

Keywords: Artificial intelligence; Machine language; Patient flow; Predictive modeling; Patient monitoring; Healthcare data

Abbreviations: AI: Artificial Intelligence; ANN: Artificial Neural Network; ARIMAX: Auto Regressive Moving Average; MRI: Magnetic Resonance Imaging; GA: Genetic Algorithm; SMART: Scalable Medical Alert Response Technology; IFPM: Intelligent Patient Flow Management System; GLM: General Linear Method; SVM: Support Vector Machine; ARIMA: Auto Regressive Integrated Moving Average; RBF: Radial Basis Functions.

Introduction

As early as in 1956, John McCarthy and his colleagues, Marvin Minskly, Claude Shannon and Nathaniel Rochester coined the term 'Artificial Intelligence' (AI). More commonly, AIis defined as, "the science and engineering of making intelligent machines [1]. Artificial intelligence refers to the computer programs that execute a task like that of human intelligence, especially intelligently and independently [2]. The main objective of AI is to develop a machine that can exhibit human intelligence.

Artificial intelligence is as a promising tool for supporting the healthcare administration. Several studies have shown that AI algorithms are capable of managing patient low and thus augmenting clinical care by reducing the administrative demands on clinicians. Artificial intelligence is not about robots completing the jobs and rendering people obsolete [3,4]. Artificial intelligence in healthcare is set to help healthcare works and stakeholders to manage the vast data and transform them into potentially life-saving information. Despite the advantages, AI applications continue to face serious challenges in healthcare (Table 1). In this review, we will focus on the role of AI in patient low management as well as in predicting the patient admission to hospital [5-8].

Challenges	Advantages
Costs of adaptation and training, and	Enables sharing of knowledge and expertise among doctors
Technological differences among hospital systems,	Improves the quality of treatment
Hesitation among medical providers to rely on AI.	Provides a better diagnosis
Mechanisms for transferring evidence into clinical practice is limited by the ever growing humongous clinical trial data	Data can be utilized for investigating a new medical solution
Requires skills in knowledge acquisition and representation	Enables better design of telemedicine application
Requires generalizable and robust data that has to be validated	Reduces the cost, time, human expertise and medical error
Building and updating the knowledge base could be hindered by lack an accuracy tracking mechanism	Improves the quality of medical decision-making
Substantial data are warranted to construct and implement automated planning and scheduling applications	Increases patient compliance
Storing remote or offline data would require substantial investment in information and technology infrastructure	Minimizes iatrogenic disease

AI applications depend on the availability of strong electronic health record systems	Minimizes the turnaround time in hospitals
The generation of large amounts of data naturally raises questions regarding the ownership of the data	Reduces patient morbidity or mortality I
	Improves the efficiency of health care delivery in terms of cost and time
	Facilitates predictions in healthcare and patient monitoring
	Plays a key role in patient management
	Holds great promise for improving the delivery of health services in resource-poor settings while it is being already being used to support and improve health services in many high-income countries
	Used to process large amounts of data from images and signals
	Used to predict, model and slow the spread of disease in epidemic situations around the world

Table 1: Advantages and Challenges of Artificial Intelligence (AI) in Healthcare.

Data and Methods

Concepts in Artificial Intelligence (AI)

Intelligence is defined by learning and reasoning. Learning is an essential element in AI and is realized through machine learning. Reasoning is another component of AI, which encompasses data manipulation to produce actions [9].

Analogy between human and AI

It is easy to understand AI and its tool by drawing an analogy between AI and human (Figure 1) [10].

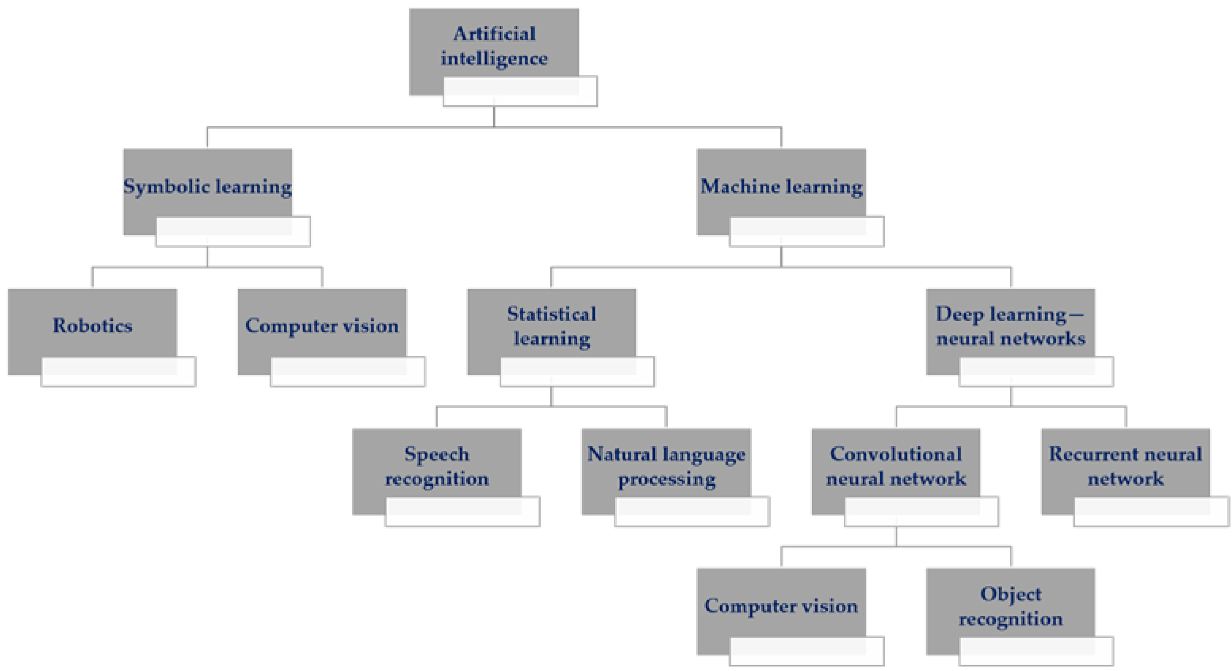

Figure 1: Concept of artificial intelligence [9].

The AI is designed to work through two ways-symbolic-based and data-based (machine learning). Humans process information through the eyes and that could be equated to the computer vision, in AI, it includes methods for acquiring, processing, analyzing, and understanding images [11]. Humans understand their environment and flexibly navigate around it. The AI counterpart of this aspect of humans would be robotics. Hence, computer vision and robotics come under a branch of AI, which uses a symbolic way of processing information. Another mode of communication is hearing-speech recognition converts speech into text using statistical models and this is called statistical learning [12]. Humans use a language to write and read and this falls in the field of natural language process, which is also driven by statistical models. Humans can see patterns and machines are much better at pattern recognition. By replicating the structures and functions of a human brain, the machines could be empowered with cognitive capabilities through deep learning-artificial neural network. The different techniques in deep learning include convolutional neuronal network and recurrent neuronal network [3]. The former works on the principle of computer vision for recognizing the objects. The human brain remembers the past events, the recurrent neuronal network enables the AI to have access to a limited amount of historical data [1].

Artificial intelligence is set to fundamentally change the healthcare for patients as well as physicians. Healthcare generates humongous data, which may be structured, unstructured and semi-structured [13], which when z, retrospectively or real-time could proactively help in patient care. Different data can be integrated through various algorithms to predict patient outcomes or hospital re-admissions. 13The available data sets would have fundamental patterns, which when analyzed can be used to predict optimal treatments, minimize side effects, and reduce medical errors or costs [14].

Types of machine learning algorithms

In AI, the algorithms are created in such a way that they can not only modify themselves in response to patterns in data set, they can also derive inferences when applied to new data.

The statistical learning can be classified into supervised, unsupervised, and semi-supervised learnings [11,14]. In the case of supervised learning, an algorithm is programmed to extract an output using an input dataset. The outcome is already predefined in the input dataset [11,14]. Automated interpretation of the electrocardiogram using a preset data on diagnosis and automated detection of a lung nodule from a chest X-ray are examples of supervised learning. Supervised learning is often used to estimate the risk (example, The Framingham Risk Score for coronary heart disease) [14]. Supervised learning includes classification and regression problems [14,15].

In the case of unsupervised learning, there is no predefined outcome to be predicted. The task here is to explore the data and discover the structure. Classifying autism spectrum disorders in children using resting state-functional magnetic resonance imaging (MRI) and structural MRI data based on random neural network clustering is an example of unsupervised learning [16]. Clustering and dimensionality reduction are the two types of unsupervised learning [14,15].

Semi-supervised learning requires the application of both supervised and unsupervised methods to derive a meaningful outcome. It explores observations where the outcome is known only for a small amount of data [15].

Predictive modeling AI in healthcare

Artificial intelligence has several applications in medicine including hospitals, clinical laboratories, and research facilities. Healthcare administration and operations; clinical decision support; predictions in healthcare; patient monitoring; and healthcare interventions are key domains where AI is applied [9].

Predictive modeling is healthcare is a proactive step towards identifying patients at risk of disease or adverse outcomes. One of the most common AI predictive model is the patient inflow into emergency department; re-admissions into emergency departments; disease or other outcomes; and in-patient mortality [17].

Applications of AI in Hospital Set-ups

Artificial intelligence has been employed for improving the operational efficiency within a hospital.

AI for improving operational efficiency

Resource optimization and patient crowding in the emergency department is a challenging issue. Resource requirement forecasting is essential to reduce the rising healthcare cost by optimizing the use and availability of healthcare resources. Yousefi et al., utilized machine learning and the genetic algorithm (GA) to determine optimal resource allocation in emergency departments. Yousefi et al., constructed a meta-model, with three power machine learning approaches (adaptive neuro-fuzzy inference system, feed forward neural network and recurrent neural network) using the bootstrap aggregating (bagging) and adaptive boosting (AdaBoost) ensemble algorithm. When applied to an emergency department, the GA algorithm was able to reduce the average length of stay by 15% [18].

Predicting the waiting time and appointment delays can help in optimizing hospital resources and increasing patient satisfaction. Curtis et al., utilized several machine learning algorithms to predict waiting times at a walk-in radiology centers or delay times at scheduled radiology facilities across all four modalities (computed tomography, MRI, ultrasound, and radiography). Several variables were extracted from the radiology information system. Nine machine learning algorithms (neural network, random forest, support vector machine (SVM), elastic net, multivariate adaptive regression splines, k-th nearest neighbor, gradient boosting machine, bagging, and classification and regression tree) were used to fine-tune their parameters into the best possible training data fit. The root mean square error metric was used to determine the predictive accuracy of the algorithms. Among the nine machine learning algorithms, the elastic net was found to be better than other algorithms in accurately and efficiently predict the waiting time and delay time [19].

Automated diagnostic decision support applications can fast track diagnostic decisions in the emergency department as well as within the hospital departments and wards [20]. Feature-rich AI models with several predictor variables were found to recognize patients at risk of experiencing an unplanned intensive care unit transfer [21]. Artificial intelligence algorithms are capable of predicting hospital readmissions within a specified duration of time and that indeed can reduce the cost in the health care system [22].

AI for patient monitoring

Integrated patient monitoring systems when paired with AI components finds application in assistive decision making [20].

Curtis et al., developed an integrated wireless system, the SMART (Scalable Medical Alert Response Technology) system to monitor unattended ambulatory patients. This system was integrated with wireless patient monitors such as electrocardiography, saturated oxygen, geo-positioning, signal processing, targeted alerting, and a wireless interface for caregivers [23]. Embedding AI algorithms within healthcare information systems can be beneficial because of its potential to improve patient outcomes, especially in busy departments such as the emergency department [24]. A web-based patient support system has been reported to reduce the cost of treatment as well as improve the quality of life of patients. Web-based patient support systems are designed to enable patient-centered decision making and physician-centered health monitoring [25]. Researchers have developed scoring algorithm to predict cardiac arrest and acute cardiac complications in patients with chest pain in emergency department [20,26].

Alin predicting patient flow

Artificial intelligence can be used to forecasting patient flow and avoid unnecessary trips to the emergency department. Rapid interpretation of clinical data would enable to segregate patients and predict outcomes in the emergency department operations. Consequently, AI directly influences the cost; efficient utilization of resources, cost and time; and quality of patient care [7]. At the time of arrival to the emergency, AI can stratify patients according to the risk and therefore facilitates efficient allocation of resources, which in turn improved patient outcomes. In the emergency department, AI can make a common diagnosis based on the radiographs and thereby accelerate the plan in patient care. At discharge, the AI can predict the possible outcomes, especially adverse events and provide a customized follow-up plan for the patient [7].

Intelligent patient flow management system: Artificial Intelligence is applied in patient flow management to predict patient flow or efficiently manage patients in the healthcare facility. The key objectives of AI in the management of patient flow are [27,28]:

- To forecast emergency department visits
- To avoid unnecessary calls and visits to the health center
- To customize a treatment plan
- To render patient flow management more efficient

A pilot study in Finland evaluated the impact of an Intelligent Patient Flow Management System (IFPM) in streamlining patient flow to hospital. The web-based system operation was based on the preliminary health issue information and symptom checking with intelligent medical diagnostics engine utilizing AI and machine learning algorithms. The primary objective of IPFM was to help patients avoid unnecessary calls and visits to their health center, and efficiently improve treatment planning and manage patient flow. The IPFM had a significant impact on healthcare cost. It was associated with a mean reduction of EUR 552,000 towards the total average service costs for 17,943 patients. A single unit cost reduction of EUR 31 translated into cost reduction towards one emergency department nurse visit (EUR 34); three emergency department nurse phone calls (EUR 10); nearly three primary care nurse phone calls (EUR 12); two primary care nurse letters or electronic contacts; one emergency department doctor consultation (EUR 35); more than one emergency department doctor phone call (EUR 23); more than one primary care doctor phone call (EUR 26); and one primary care doctor letter or electronic contact. The researchers concluded that an IPFM may reduce service costs in primary care setting [27].

Predicting bed availability: Within the realm of management of patient flow, access to beds is one of the most challenging tasks for a hospital. A combination of administrative data about bed usage with clinical data about the patients can help in predicting patient discharge and bed availability. The predictive power of AI can enable staff to schedule surgeries on the basis of availability of bed. Thus AI can ensure better utilization of the hospital's resources as well as provide opportunity to generate higher revenues [29]. Wise-ward is a solution that helps achieve these goals using predictive analytic [29].

Predicting seasonal flow of patients: Besides patient and hospital factors other environmental factors also determine the patient flow to the hospital. Marcillo et al., found that calendar variables were considered as more important forecasting factors than ambient temperature. Weekly seasonality was more dominant than monthly seasonality. The forecast models used by Marcilla et al., were based on three time-series models, namely, generalized linear models (GLM), generalized estimating equations, and seasonal autoregressive integrated moving average (SARIMA) [30].

Patient flow prediction models

Prediction of patient flow will help in optimizing hospital resources, improving operational planning, and, improving healthcare quality, planning and allocating hospital resources, increasing patient satisfaction [31,32]. Various forecasting methods that have been employed in predicting patient flow include linear regression, SARIMA, exponential smoothing, time series regression, and artificial neural network [28]. A few studies have attempted to predict patient flow to the emergency department or the outpatient using AI.

Knowing the fluctuation in the volume of patient arrival in advance will help in taking off the stress of healthcare personals. Jiang et al., used a GA-based feature selection to compare the outcome with standard traditional forecast models (GLM, Auto Regressive Integrated Moving Average [ARIMA], and classical shallow artificial neural network [ANN]). However, these models work well when the prediction is based on one-week historical daily patient arrival data. The accuracy of prediction of these model declines if the prediction horizon is more than one week and hence fail to meet the demand for long-term decision making. In this context, Jiang et al., used a deep learning framework (Deep Neural Networks [DNN]) to predict the daily and hourly arrival volume of patients under different severities with a prediction horizon of 28 days. The researchers accessed 245,377 patient records from 1st July 2009 to 31st March 2011 and obtained the daily and hourly volume. The data from 1st July 2009 to 22nd October 2010 were used for feature selection and hyper-parameter validation (around 70%) and the rest (from 23rd October 2010 to 31st March 2011) for performance testing. Based on the hospital triage system, patients were divided into five categories. Compared with other widely used prediction models, DNN-I (integrated)-GA achieved the highest accuracy with the lowest variance, which reflects its high-robustness [31]. The GA-based feature selection algorithm was improved by incorporating a fitness-based crossover. The improved GA-based feature selection algorithm outperformed a typical GA and four state-of-the-art feature selection algorithms (selection algorithm with minimal-redundancy-maximal-relevance framework, a simulated annealing-based wrapper feature selection algorithm, a variable importance-based feature ranking algorithm, a correlation-based feature ranking algorithm). The proposed integrated DNN-I-GA framework achieved higher prediction accuracy on the root mean square error and mean absolute percentage error metrics compared to the standard statistical models (GLM, seasonal-ARIMA, Auto Regressive Moving Average (ARIMAX), and ANN) and modern machine models (decision making SVM with radial basis functions (RBF) kernel [SVM-RBF], support vector machine with linear kernel [SVM-linear], random forest, relaxed LASSO [R-LASSO]) [31].

Discussion

Early identification of patients in the emergency department requiring admission may perhaps help in optimizing the hospital resources. Hong et al used triage information and patient history to predict hospital admission at the time of emergency triage. In general, the prediction of patient admission to ward from the emergency department was based solely on the triage (demographics, vital signs, chief complaint, nursing notes, and early diagnostics). Triage-based prediction models include the Sydney Triage to Admission Risk Tool and the Glasgow Admission Prediction Score. Hong et al. used 972 variables extracted per visit from the electronic health records. Logistic regression (LR), gradient boosting (XGBoost), and DNN were trained on three dataset types (only triage, only patient history and full set (both triage and patient history). The addition of historical information to triage information significantly improved predictive performance significantly vs. triage information alone. Moreover, XGBoost and DNN were better than LR in predicting hospital admission when the full dataset was used. The predictive value of XGBoost and DNN across all three dataset types was similar. Hong et al showed that the addition of patient history to the triage information could enable machine learning to strongly predict hospital admission [32].

Bayesian learning refers to application of probability theory to learning from data. Bayesian probabilistic modeling forms the basis for rationality in AI systems and also serves as a model for normative behavior in humans and animals [33].

Conclusion

The application of AI ranges from hospital administration to therapeutic decisions. Artificial intelligence is changing the medical landscape. The AI is designed to work through symbolic-based and data-based (machine learning). Computer vision and robotics uses symbolic- based data to process the information. Artificial neural network is a data-based AI that is enabled with cognitive capabilities of a human. Healthcare generates humongous data, which may be structured, unstructured and semi-structured. These data will be redundant unless it is interpreted and integrated into various algorithms, especially to predict outcomes. In AI, the algorithms are created in such a way that they can not only modify themselves in response to patterns in data set, they can also derive inferences when applied to new data. In lieu of availability of humongous data, several predictive models have been developed in the context of healthcare administration and operations; clinical decision support; predictions in healthcare; patient monitoring; and healthcare interventions. AI has been applied to predicting the flow of patients into the emergency department; streamlining patient flow to hospital; monitoring patients in ward and emergency department and predicting the availability of bed in in-patients. Various forecasting methods that have been employed in predicting patient flow include linear regression, exponential smoothing, time series regression, and artificial neural network. Bayesian network is a probabilistic model.

Artificial intelligence seems to be an ideal tool for optimizing patient management in hospitals. A wide range of AI algorithms are available for managing and predicting patient flow into the various departments of a hospital. Despite available evidence on the use of AI in patient flow management, the application is still in infancy. Future studies are warranted to practically use AI in patient flow management.

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