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REVIEW

Artificial intelligence assisted food science and nutrition perspective for smart nutrition research and healthcare

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Abstract

Artificial Intelligence (AI) has the potential to dramatically change the field of healthcare and nutrition by imitating human cognitive processes. This field involves smart machine-based applications, such as Machine Learning (ML), neural networks, and natural language processing to tackle and solve various issues. The current study's purpose is to highlight specific AI-based applications that are currently being employed in the fields of nutrition and healthcare. The published data from various search engines, such as PubMed/Medline, Google Scholar, Scopus, Web of Science, and Science Direct, were used for collecting the relevant data. The study depicts that there are several AI-based approaches and methods available for by improving diagnosis and treatment, lowering costs, and increasing access to healthcare facilities. Although AI cannot replace the personal touch, empathy, and emotional support provided by healthcare professionals. These approach assistances expanding rapidly are of great use. However, it is crucial to be careful and make sure that moral considerations are given top priority.

Keywords Artificial intelligence · Machine learning · Nutrition · Healthcare · Neural networks

Introduction

AI is one of the rapidly developing fields. Due to its ability to mimic human intelligence, it is one of the most exciting and talked about technologies in the past decade. As there are limits to human intelligence, as a result, there is a demand for AI, a technology that, when included into a system, allows it to develop intellectual capacities, which may help people pursue greater human advancement [1]. According to John McCarthy [2], AI is the science and engineering of building intelligent machines and intelligent computer programs. This field of knowledge involves intelligent machines that uses ML, neural networks, and natural language processing to tackle and solve various issues. Also, automobile, logistics, healthcare, stock trading, robotics, finance, transport, radiology, genetic, and education are among some of the areas that employ AI extensively [3]. It is revolutionizing all spheres of existence, including governmental policy, science, psychology, medicine, and nutrition [4]. AI has a positive impact on the field of nutrition and it is playing a crucial role in continuously enhancing this field. Several research scientists have utilized the concept and applications of AI for testing the composition of food products, determination of microminerals in several vegetable and pharmaceutical samples using radial basis function, and ANN and genetic algorithm (GA)-based optimization of possible anticancer agents in fermented wheat germ. Researchers also demonstrates the use of AI models in the study of biomedical nutrients and vitamins [5, 6].

The potential for advancement and use in nutrition provided by AI is unparalleled as it provides several opportunities in this field. Increasingly, these new computational tools are being used in the field of healthcare, particularly in the area of nutrition research due to the large and complicated quantity of data collected in the area. The advancement and development of nutritional assessment tools have been aided by AI-based methodologies, and this has resulted in improved prediction of health outcomes based on dietary

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exposures [7]. AI technology started to augment the fields of food science and nutrition research in the late 2010s. By far, there are several technological advances that took place in food science and nutrition, such as personalized nutrition, automated control of diets and recipe evaluation, testing sustainability of food, precision medicine improving the disease diagnosis, and parenteral nutrition decision-support tool development and remote nutrition evaluation using telehealth and wearable technologies and mobile applications dealing with nutrition [8, 9]. By providing individualized dietary advice, optimizing food production and distribution, and facilitating more accurate and efficient research, AI has the ability to revolutionize the nutrition. To find patterns and correlations that can inform dietary recommendations and personalized nutrition, AI can be used, as it can easily evaluate massive databases of dietary and health information. AI can also be used to evaluate how different substances and nutrients affect the body, which can be helpful for researching and developing new foods and supplements according to individual needs [10]. Recently, AI has also been utilized for depression detection, and for COVID-19 patients, it has been shown that Ensemble Deep Learning (EDL) is a highly efficient for identifying depressive symptoms in cross-domain scenarios and for the classification of COVID-19 patients [11, 12]. Several applications of AI are being utilized to analyze, interpret, and evaluate enormous amounts of data, including medical records, dietary surveys, and genetic information. AI is anticipated to play an even bigger role in enhancing human nutrition and health in the future. AI systems are used to more fully comprehend and forecast the intricate and non-linear relationships between nutrition-related data and health result, especially when data are large [13]. This shows that AI is a rapidly emerging field that presents unmatched prospects for advancement in nutrition and likely to enhance nutrition research by assisting the investigation of novel applications.

Overall, AI has the ability to enhance public health and quality of life by promoting improved health outcomes through dietary advice and more effective food systems. Looking at such vast implications and prospects for future use of AI, this paper aims on critically evaluating the recent literature on AI in the fields of nutrition and healthcare. It emphasizes the usage of certain AI-based technologies that employ ML and DL.

Review methodology

The most relevant studies on AI-based technologies being applied to the field of nutrition and healthcare were examined to carry out this comprehensive study. We searched for scientific data published in online databases, such as PubMed/Medline, Google Scholar, Scopus, Web of Science, and Science Direct using MeSH terms “AI’, “Nutrition”, “Healthcare”, “Food recognition,”, “Obesity”, “Cancer”, “Deep learning”, “Machine learning”, “Neural networks”, “Diet therapy”, “Nutritive values”, “Nutritional quality” and “Nutritional availability”, “Nurse AMIE” in English language. After screening articles and papers relevant to the topic were included, while literature available in other language, nonrelevant, and duplicate articles were excluded.

Technologies involved in AI and their applicability in the field of nutrition

Machine learning (ML) and deep learning (DL)

Many technologies are included in AI nowadays. The current development in AI is attributed to two significant subfields which includes ML and DL that have recently received attention [1]. Figure 1 explains the relationship and connection between the three fields. In AI, computers complete the tasks with accordance to predetermined rules and algorithms. ML is a subfield of AI and consists of all techniques that let computers learn from data without being explicitly programmed. Moreover, a subset of ML is called DL it includes computer models and algorithms that mimic the structure of the biological neural networks in the brain [Artificial Neural Networks (ANNs)] [14].

ML is self-learning which is based on algorithms, the system learns by doing. For example, the system recognizes patterns in the input data it receives and adapts at the output based on what it has learned. As a result, the system continues to advance in intelligence without any human input. It makes use of a statistical learning system that continuously develops on its own without assistance. On the other hand, a DL system learns from experience, but it also receives a lot of input in the form of a big database. Deep neural networks have multiple layers between their input and output [15].

Artificial neural networks (ANNs)

ANNs, a modeling technique, are widely employed in the field of AI. The structure of human brain's natural neurons served as inspiration for ANNs. The purpose of ANNs is to process and calculate input signals using rows of processing components known as artificial neurons that are connected to one another via artificial synapses [16]. Neurons are frequently arranged into networks with several layers. An input layer gets the data input (example, product photographs from an online store), and an output layer generates the final product (example categorization of the products). There are zero or more hidden layers in between that determines a non-linear input-to-output mapping [17]. An ANN shows its specific value when modeling datasets with

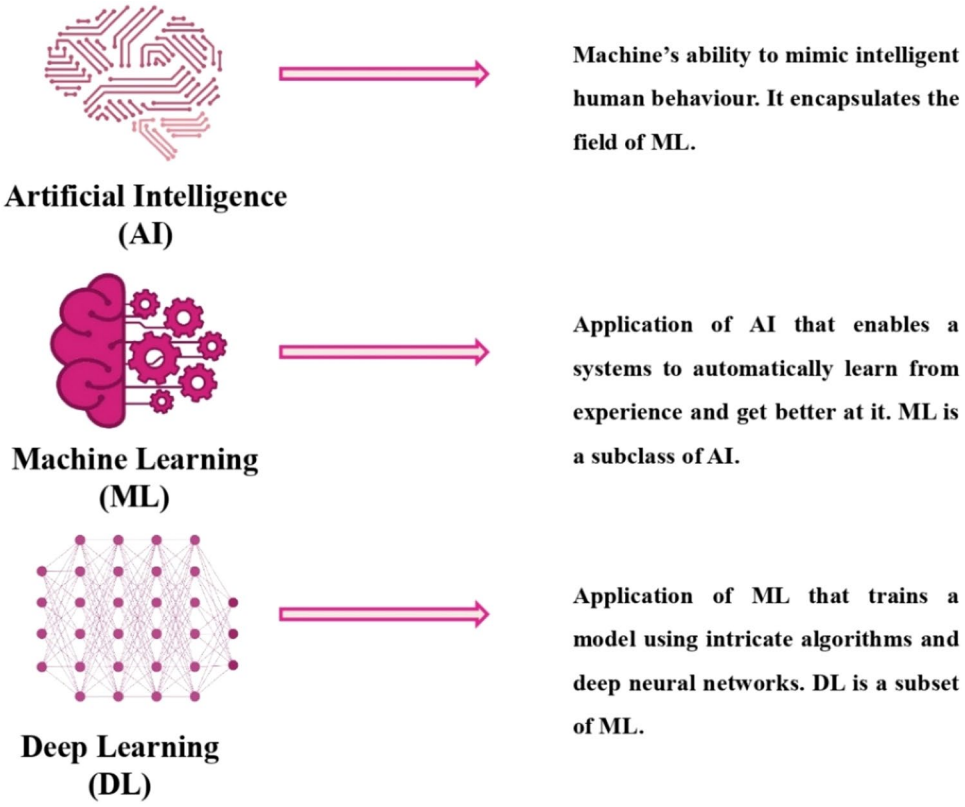

Fig. 1 Relationship and connection between AI, ML, and DL

non-linear dependencies is required. The concept of ANNs is widely used in the field of nutrition science; one such application involves the prediction of association between the Mediterranean food pattern, clinical traits, and cognitive functioning [18]. It is also being utilized in the study of body composition. In the field of clinical dietetics, ANN modeling has the potential to yield major advantages [6]. Several research studies show the application of ANNs in the clinical setting. Thara [19] and Kather et al. [20] employed DL-based ANN to develop a variety of blood tumor markers based on ANN models for gastric cancer. This ensured a greater specificity while increasing the diagnostic sensitivity, demonstrating the high value of the ANN model in the early diagnosis of gastric cancer. Studies also show that compared to a single serum marker carcinoembryonic antigen (CEA), the ANN model is more accurate at predicting colorectal cancer [21]. The concept of ANN is also utilized by the scientist to prevent the overweight and obesity. These are the lifestyle-related problems which are widely associated with consumption of high amount of sweetened carbonated beverages. To monitor the actual consumption per serving and to develop self-monitoring of the actual consumption, an image-based tool was developed using the concept of ANN. This method includes the classification of beverage and then providing the nutritional information per serving, such as calories, fat, sugar, etc. [22]. All these applications suggest that the ANN are strong models with varied application, such as image processing, forecasting, and character recognition, and can be used extensively in the field of nutrition and dietetics. The general structure of ANN is shown in Fig. 2.

Internet of things (IoT)

The 'Internet of things' (IoT) is a developing network of items that use the Internet to connect with one another and other devices that uses internet. Using IoT, we can remotely manage and monitor the physical environment [23]. Among the most well-known innovations that developed in recent years is IoT, which has gained popularity due to its significance and ability to actually improve things for better. With IoT a new technological future has arrived, since it has altered technical realities and made it imperative to re-invent

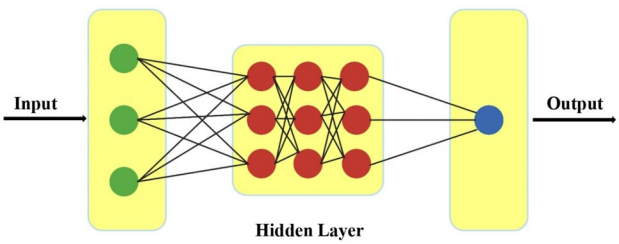

Fig. 2 Structure of artificial neural network (ANN)

computing. It is becoming popular because of the opportunities it offers, such as quick and advance monitoring, personalized recommendations, automatic food tracking, and smart appliances [24]. This is the idea that through a computer network or intelligent electrical devices, sharing and gathering of data can be done. A network of individuals, organizations, systems, and objects that are all connected to the Internet is referred to as the 'Internet of everything' (IoE). IoT has a considerable applicability in clinical practice in regard to telemedicine procedures, which are being employed frequently, especially during the COVID-19. Major uses of IoT include providing comprehensive data on food products that are currently available in the market [25]. The concept of IoT is widely employed in the field of nutrition and dietetics as it is used in diet monitoring and tracking, and various models have been developed using this technology. One such example is completely automated diet monitoring system made up of Wi-Fi powered sensors for assessing nutrient intake and a smartphone app that gathers data on the nutrition of food ingredients. The monitoring device has a food weighing sensor built in, which determines the weight of the food item and sends it wirelessly to the cloud over the Internet, the food is then categorized according to its highest nutritional value and the connection between the nutrients it has and the nutrients it lacks. This helps to predict the nutrient deficiency and obesity [26].

In diet monitoring using IoT, the food item is recorded, and statistics are computed to help provide a complete report for the consumer and provide them with the appropriate guidance. By examining the food analysis, we can precisely decide that the food is nutrient-dense and suitable for human consumption based on the mechanism that explains nutrients that are highly recommended and the items that cause obesity [27]. All these applications shows that the food business and nutrition field are gradually becoming familiar with the IoT. As it has a number of significant applications that are giving food producers, nutritionist, processors, and merchants' unprecedented opportunities. Several other examples reflect the widespread and dynamic nature of IoT in this area, such as an IoT-based soil nutrition and plant disease detection system that uses a variety of sensors to gather plant-related data in the form of images at various time intervals. Soil sensors are also used to test the soil's fertility, which aids in determining the soil's suitability for harvesting or for new cultivation [28]. Smart health which is a system basically used for automatic monitoring of nutrition is another example IoT-based system benefiting the field. It includes Wi-Fi connected sensors for measuring food nutrition and a smart phone software that compiles nutritional information about the food's constituents [29].

Not only in nutrition IoT is wide spreading in healthcare systems also, IoT in healthcare uses software and technology to connect patients and healthcare professionals. Heart rate monitors, smart beds, and electronic wristbands are just a few examples of the IoT devices used for health monitoring [10].

The scope of the deployment, the complexity of the system, the quantity and kind of devices involved, as well as the individual project needs, can all have a considerable impact on the cost of adopting IoT solutions. The economic aspects include cost of infrastructure, hardware, development of software, connectivity, implementation, and support cost which may vary [30].

Potential role of AI in nutrition

Digital technology is now deeply ingrained in society as a result of its rapid advancements in power and practical utility. Nowadays, digital technology is used in practically every industry even those unrelated to technology to gather data, do computations, and automate processes. In the field of nutrition and dietetics AI is used to diagnose illness, assess clinical outcomes, and develop innovative medicines and therapeutic modifications [31]. As medical industry is growing day by day, there has been a growing interest in using core technologies in the field of nutrition. These technologies provide precision in dietary intake, interpretation, and capacity to produce useful feedback. AI-based concepts are utilized for the prediction of nutritive value, and Smith et al. used ML-based approaches for forage analysis to predict nutritive value, such as dry matter, fiber, ash, in vivo dry matter digestibility, crude protein, and soluble carbohydrates [32] Sandhu et al. applied AI approach to increase the nutritive value fried fish. The combination of cooking parameters was optimized using ANN model-based meta-heuristics, stochastic optimization formalisms, genetic algorithm, and particle swarm optimization (PSO), which increased the PUFA and SFA profile up to 63.05% resulting in enhancing the nutritive value [33].

Farmers are able to get more productivity of various crops per acre with better nutritional using AI-powered technologies. Farmers are now able to produce more crops per acre with better nutritional quality because of AI. Leading technical advancements are being used to meet the growing global food demand [34]. AI can assist increase the nutritional quality of crops by enabling accurate and data-driven farming processes, which take into account elements like nutrient content, pesticide use, and harvesting procedures. Precision agriculture is a high-tech approach; it measures the precise amount of manure required for the soil and limits release of greenhouse gases which increases the crop production and yields a crop with high nutritive value [35]. The nutritional quality and availability of a food is seriously affected by adulteration. Food adulteration is a dishonest practice used to deceive consumers to earn profit from the sale of food.

Due of the risk to public health, decline in food quality, or loss of nutritional content, it has been a serious concern [36]. Large amounts of food-related data, such as chemical composition, sensory characteristics, and historical records, can be processed by AI systems. AI can find trends and anomalies in these data that might be signs of adulteration [37].

The applications vary from use of mobile apps to monitor dietary intake, wearable devices such as smart watches to collect data, and use of telehealth for remote nutrition assessment [38]. There are several mobile applications that deal with the management of weight loss. Some popular examples include Cronometer, MyFitnessPal, and Noom. They include functions like food tracker, exercise, psychology, and behavior change practices to implement loss of weight [39]. Also, there are certain mobile applications dealing with the management of diabetes and gastrointestinal conditions, such as Day Two, Glucose Buddy, Dario Health, Cara care IBS, Gali health: IBD and My symptoms. These applications basically deal with the diet tracking, glucose tracking, education and coaching, tracking bowel movements, pain, GI symptoms and generation of reports, and sharing with the health care workers [40].

Certain domains of AI utilized in the field of nutrition and clinical setting are shown in Fig. 3 which includes food image recognition, diet optimization, dietary pattern assessment, prediction of risk factors, diet planning, and advancement. DL is often used for image recognition. DL has been applied to the analysis of medical images, including endoscopic images for the detection of colonic polyps, radiographic images for the diagnosis of pneumonia, and cutaneous images for the detection of melanoma [40, 41].

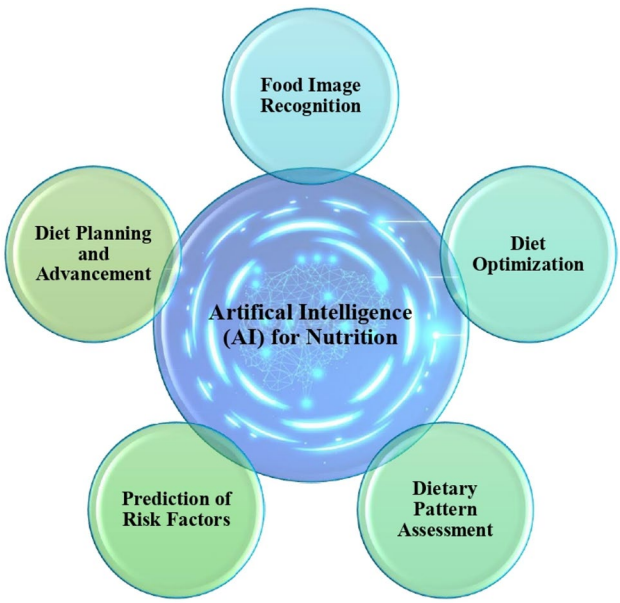

Fig. 3 Domains of AI in the field of nutrition

Food picture identification would be a logical use of DL in the field of nutrition [42]. Diet optimization techniques are used to develop diet programs that adhere to predetermined nutritional and financial limits while closely resembling current eating patterns. Masset et al. [42] show the mathematical optimization techniques to dietary recommendations for cancer prevention. The optimization models define lower and upper consumption limits according to the eating patterns of the individual to prevent excessive amounts of any one meal or food group. The benefit of machine learning, on the other hand, is its capacity to analyze enormous amounts of high-dimensional data to spot complicated patterns that would otherwise go undetected; this property is utilized for the prediction for risk factors associated with various diseases [43]. Today's clinical diagnostic AI algorithms are trained to do a specific task, such as classifying photos of skin lesions into diagnostic categories or generating a molecular diagnosis [44]. Applications of computer vision to medical scans have accounted for majority of the early applications of AI in healthcare that the US Food and Drug Administration (FDA) has approved; these include MRI, tomography images, mammography, automatic detection of diabetic retinopathy, and many more [45, 46]. AI is anticipated to provide diet-planning solutions through the automatic and effective application of expert knowledge to handle the complexity of optimal diet design. Applications powered by ML for automatic diet planning are considered a major advancement in the field of nutrition and dietetics [47]. There are a number of technologies and digital applications based on AI that can significantly reduce the burden of dietary monitoring as opposed to the conventional approaches, which require users to look up the nutritional value of foods in a calorie book and then manually input the information in a log book [48].

AI-based digital innovation for diet

Monitoring and reporting the food consumption and eating habits are a crucial step in improving the diet. Unfortunately, traditional food monitoring techniques rely on flawed self-report assessments which are sometimes problematic. The example includes most commonly used 24-h dietary recall, food frequency questionnaire, and food diaries. The problem faced while using these methods involves lack of memory recall while recalling food consumed, manual entry of data, and under-reporting of data. Mobile applications for diet logging, new wearable sensors to monitor dietary behaviors, and individualized nutrition programs based on evaluating biochemical markers through AI techniques are some of the currently used techniques [49, 50].

Smartphone application for diet monitoring

The transition from paper-based publications to the use of smartphone applications has been a significant step of improvement for reducing burden of diet monitoring. These are having a more practical approach as the users do not need to carry a log book or entry book. The applications also give users access to databases that list the nutritional value of a huge variety of foods and meals [48]. One such example is MyFitnessPal app. There are about 11 million food items on this app. Having access to such big databases makes it much easier for users to make decisions about portion sizes and meals by offering accurate nutritional information about meals [51]. The ability of mobile apps to scan barcodes for packaged items eliminates the need to manually enter food nutrients or search for the food in a database, which is another benefit of mobile apps. Also dieting apps can be coupled with external devices like glucose monitors, smart scales, fitness trackers, and fitness monitors to assist users evaluate the impact of diet and exercise on their glucose patterns and weight trends [52]. Another smart technology use includes the photographic food diaries that has gain popularity over the last 10 years. They are much better as compared to the written diaries as they promote present awareness and more precise memory. Also, they are preferred more due to ease in useability [53]. There are several apps that utilizes the technology of photographic data; for example, glucose information from Continuous Glucose monitoring's (CGMs) is combined with photo-based food information in the diabetes app Underyfork. A growing number of commercial apps, such as Lose It, Snaq, Protein Tracker, CalorieMama, See how you eat, MyPlate, Fooducate, etc., use the concept of photo-based food diaries [54].

Image-based food recognition system (IBFRS)

A diet that is unhealthy and unbalanced can harm our health and increase our risk of developing chronic and fatal diseases. Nutritionists or dietitian encourage consumers to keep a manual record of the meals and liquids they consume each day to ensure consumption of balanced diet. All the traditional methods of dietary assessment such as dietary recall and food frequency questionnaire, although are effective and economical but are very time-consuming. Thus, to make food habits monitoring more objective and precise, automatic monitoring techniques can be quite important. Many automatic record-keeping methods have been suggested to enhance food intake monitoring [55]. IBFRS use computer vision techniques and the mobile camera for the dietary assessment. The steps included in IBFRS are (1) the person takes picture of the upcoming meal using the mobile camera, (2) the second step includes prepossessing; in this step, foods are separated into categories using segmentation algorithms, (3) third step include feature extraction, (4) in the fourth step, food classification takes place, (5) in the last step, volume of each food is calculated and on the basis of that nutritive value of the meal is obtained [56]. These steps are shown in Fig. 4.

This method also has some limitations such as errors in measurements due to live conditions such as poor lighting while taking the image or forgetting to take to picture before consuming the food. Research efforts are already aimed at minimizing the sources of such errors, such as with the use of automatic text messages on the user's device [57]. IBFRS can, therefore, be a simple and reliable technique for dietary assessment.

Sensors for monitoring food and nutrition

Along with the use of mobile apps for tracking nutrition, many sensor-based methods are also being utilized to automate the process of food tracking. They are broadly classified as physical and chemical sensors [50]. Physical sensors can either be in form of wearable sensors or smart utensils. Wearable sensors, such as electromyography (EMG), piezoelectric, and acoustic sensors, are utilized to monitor the movement of the muscles around the mouth and to detect chewing and swallowing sounds to improve food intake detection. Eyeglasses with EMG sensors can recognize eating and swallowing actions [48]. Physical sensors have also been included into plates and cutlery, because wearing a lot of sensors may be bothersome. If these 'smart utensils' are equipped with additional sensors, they can also detect when someone is eating and identify the food and its ingredients [58].

On the other hand, chemical sensors are used to determine dietary indicators that are connected to nutritional intake. There are biomarkers that have found to be associated with the consumption of different foods like fruits, sugar or protein such as vitamin C in blood, urinary glucose, and nitrogen [59]. The Biosense monitor and the Ketonix analyzer are the two of the breath ketone meters available in market. These chemical sensors are intended for people who want to reduce weight by following ketogenic diets, but they may also be helpful for those who have diabetes [60]. Few other examples include CGMs, sweat and saliva analysers for glucose, and body fluid monitoring, respectively [48]. Table 1 shows the application and benefits of AI-based concepts in nutrition and healthcare.

Overview of artificial intelligence and healthcare

Lately, AI techniques have had a profound impact on the healthcare sector. In certain functional areas of healthcare, AI can help doctors in coming up to a clinical conclusion.

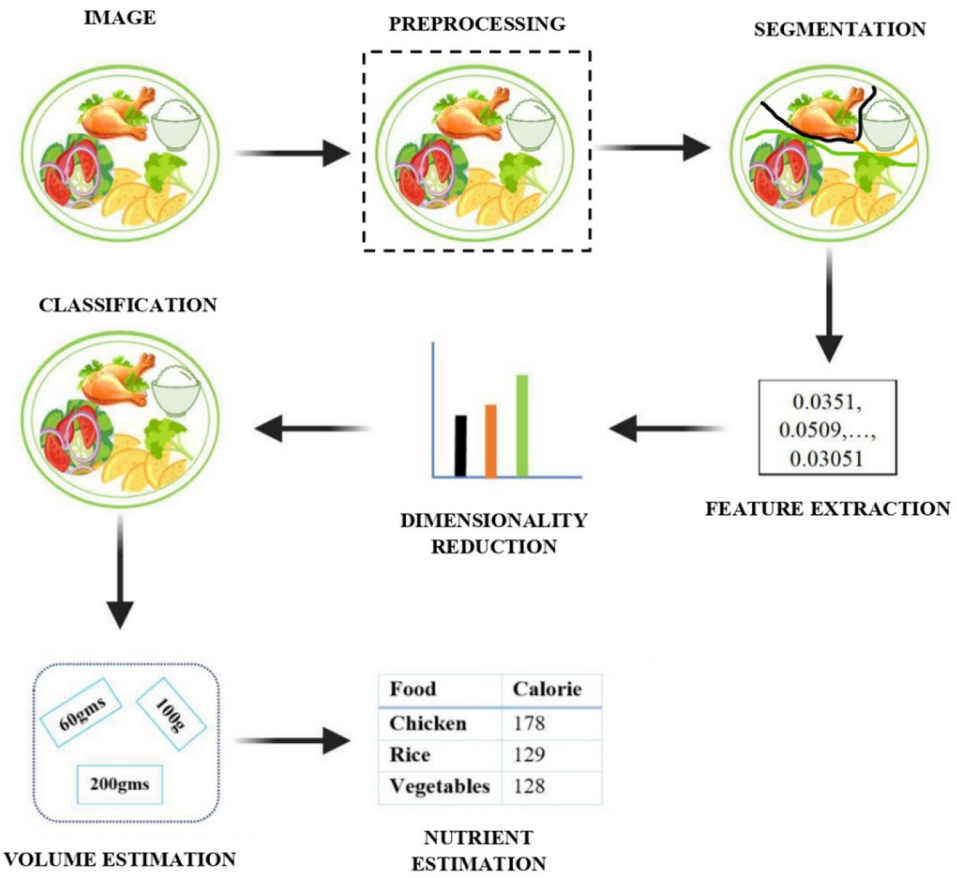

Fig. 4 Steps included in IBFRS

The recent effective implementations of AI in healthcare have been made possible with the help of rapid advancement in data analytical methodologies [74].

The answer to the question why to use AI in healthcare is that the chances of unavoidable error in diagnostic, clinical, and therapeutic practice can be tackled. AI system can help doctors and clinical practitioners by providing them current medical information from various sources, such as journals, books, etc., to guide correct patient treatment [67]. The area of medicine can benefit greatly from the application of AI, which comprises the domains of ML, natural language processing, and robotics. It is useful for the purpose of diagnosis, medicine, clinical applications and many more. Certain examples include human avatars for the treatment of psychiatric problems, robotic prostheses, telemedicine, etc. [75]. AI programs can handle the enormous quantity of data generated in discover new information; also, these technologies can find novel medications for patient care [76]. According to several studies, AI is currently capable of performing crucial healthcare jobs including disease diagnosis. Algorithms are already being used in detecting dangerous tumors and helping the researchers build cohorts for expensive clinical trials. Precision medicine is one use of machine learning in healthcare, and it involves predicting what procedures are most likely to be effective for a patient depending on a variety of patient characteristics and the treatment. Another AI approach includes Neural Networks; it is utilized in the field of healthcare for classification purpose to know the probability of acquiring a particular problem or disease [10].

A study conducted by Connelly et al. [66] states that the number of surgeries utilizing robot assistance has significantly increased recently. The research work shows that how robotic-assisted surgery has become more common in a variety of medical specialties, including urological, colorectal, cardiothoracic, orthopedic, maxillofacial, and neurosurgical [66]. Several other studies shows that the concept of ML and data mining can be applied to solve public health problems, psychological problems, ocular conditions, and identification of risk factors. The use of AI in diagnosing and treating illnesses is widespread. AI is being utilized for medical image analysis, including those of X-rays, CT scans, and MRI scans. Medical professionals may diagnose diseases like cancer, heart disease, and neurological illnesses more swiftly and accurately with the use of AI algorithms [77]. AI is being used in personalized medicine to analyze patient data, including genetics, medical history, and lifestyle factors to create individualized treatment recommendations. This results in more precise and effective in illness therapies [78]. To find potential new medication, AI is being used as it can to analyze enormous amounts of data. This could speed up

Table 1 Application and benefits of AI-based concept in the field of nutrition and healthcare

AI-based concept	Application	Benefits	References
DL	Radiology pictures	Diagnosing and treating cancer at an early stage	[61]
DL	Radiomics, oncology-oriented image analysis	Detecting alterations in tumor size, shape, and texture	[62]
ANNs, DL	Natural language processing (NPL)	Virtual assistants, chatbots, voice-activated gadgets, and language translation	[10]
Robotic process automation (RPA)	Used for repetitive tasks	Better productivity, accuracy, scalability and cost savings	[63]
ML	Radiological image analysis, retinal scanning, genomic based precision medicine	Recognizing patterns and irregularities	[64]
Machine learning	Genetics and electrophysiological (EP)	Increase the precision and speed of analysis	[65]
ML, DL, computer vision, RL	Surgical procedures utilizing robotic surgery	Precision movements, better view of the surgical field	[66]
Convolution neural network (CNN)	High dimensional data	Identifying a skin lesion's, retinopathy, microaneurysms and hemorrhages	[67]
DL, ML	Assessment of dietary intake (macronutrients)	AI evaluate the types and quantities of macronutrients	[68]
ANN, ML	Monitoring of trace elements	Delivering faster, more accurate, and efficient monitoring	[68]
IoT, ML, DL	Techniques of physical assessment	Analyzing the data gathered using direct and indirect method of assessment	[69]
ML	Geriatric clinical nutrition	Personalized diet planning, medication management, disease management	[70]
ML, DL	Maternal health care	Using digital technologies increasing access to quality care	[71]
ML	Prediction of risk factors associated with obesity	Predicting the associated risk factors	[72]
CNN	Nutritional status assessment (automatic calorie intake determination)	Image analysis, portion and calorie estimation	[73]

the search for novel drugs and result in the creation of fresh medical approaches [79]. Predictive analytics utilized AI-based applications to examine patient data identify high-risk individuals. This enables medical professionals to take quick action, so that disease progression can be prevented [80]. AI-powered virtual assistants are able to inform patients about their diseases, medications, and available treatments. This results in improved patient care management [81].

Despite a growing amount of literature on AI and healthcare, the research primarily focuses on a few diseases which are the following:

AI and cancer

A number of studies show the use of AI-based technologies for cancer patients. For example, Stephanie et al. [82] worked on the development of chatbot to teach young adults with cancer positive psychology techniques. Current research has also made use of smartphone applications to assist people with breast or prostate cancer [83]. Metastatic breast cancer (MBC) also known as advanced or stage IV cancer occurs when cancer cells spread to other parts of the body. Approximately more than 150,000 women in the US are living with MBC presently. MBC can significantly lower quality of life and cause psychological and physical problems. Moreover, MBC has a large financial impact on society [84]. The rates for MBC survival are improving but still the burden of after effects and treatment is very high. Nurse Addressing Metastatic Individuals Everyday (AMIE) is an AI technology-based supportive care platform focused on self-care and navigation. This program aims at providing routine evaluation of the patient symptoms, psychological behaviors, and functional assessment through various channels, such as YouTube videos, healthcare phone calls, exercises, and consultations [85]. The study done to assess the accessibility and feasibility of AMIE among people with metastatic breast cancer shows that it was well accepted and utilized by approximately 68% of the patients [86]. After a gastrectomy, patients with gastric cancer must have a personalized survival estimate. As most patients undergo major dietary change, muscle loss, and surgical alterations in the first year following gastrectomy, this period is time to predict long-term survival [87]. Precision medicine and individualizing patient prognosis are becoming more important as the

percentage of long-term survivors rises. Several AI-based prognostic models were developed to determine the patient survival post-surgery [88].

Figure 5 shows the functioning of Nurse AMIE. Interventions that would enable metastatic breast cancer patients to self-manage their symptoms without necessitating additional clinic visits are desired by these patients. The Nurse AMIE intervention's technology-based approach has the potential to alleviate inequities in the delivery of supportive care, because it can potentially reach MBC patients who are medically underserved and are from underprivileged socioeconomic backgrounds [89].

AI plays an important role in assisting the nutritional needs of a cancer patient, chemotherapy-treated cancer patients experience nausea at times, and hence, it is crucial for them to eat properly to combat both their disease and the effects of chemotherapy on their bodies. AI-based approaches are used for dietary recommendations of each patient by taking into account the particular nutritional requirements and potential side effects of cancer therapy. For instance, AI can suggest nutrient-rich foods that support the management of side effects of the treatment, such as nausea, taste alterations, or weight loss. To create a balanced, wholesome, and palatable meal plan for the user, a number of preferences are specifically applied to evaluate meal components [90].

AI and obesity

Looking at the current scenario, certain behavioral factors, such as lack of balanced diet, sedentary lifestyle, and unhealthy eating habits, are major contributors toward obesity and overweight. They are the most common lifestyle disease which further leads to development of other problems,

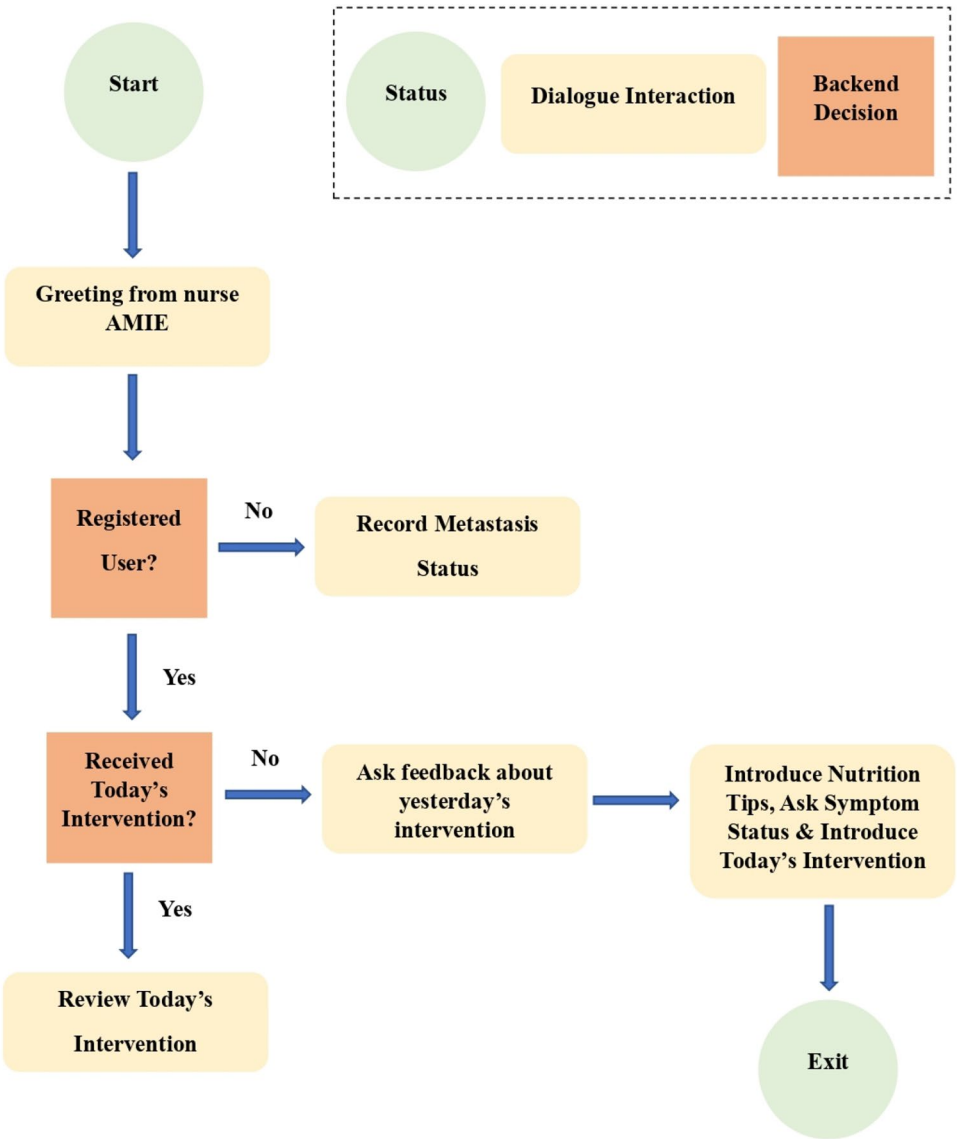

Fig. 5 Functioning of nurse AMIE

such as cardiovascular disease, hypertension, cancer, diabetes, depression, and many more [87]. Over in the last 40 years, the prevalence of obesity and overweight among children and adolescents has increased significantly. Predictive algorithms to identify those individuals at high risk is of obesity can be very helpful in preventing this problem. As a result, preventive actions can be targeted at the high-risk group, providing for a more individualized and cost-effective approach toward weight management [91].

Obesity in children has emerged as a serious public health issue. According to studies, the prevalence of childhood obesity has risen recently. According to WHO statistics, nearly 30% of the deaths by 2030 will be mainly because of lifestyle-related illnesses [92]. Determining the obesity trends during childhood in early life might avoid future health problems; therefore, early preventative interventions are crucial. Children who are obese are at risk for major lifestyle-related disorders in adulthood [93]. To enable early interventions, models for estimating the likelihood of childhood obesity are needed. AI has the potential to be used for this purpose. Presently, WHO growth charts are most commonly used to determine childhood obesity. However, these charts only show the child's current level of obesity; they cannot be used to predict the child's future obesity category, i.e., they cannot predict the child's obesity level at age 5 [94]. This demonstrates the necessity of creating data-driven ML models that can be utilized to predict a child's future obesity category [3]. The capacity of ML algorithms to find hidden trends and patterns in data is one of its strongest points. The statistical and ML techniques have a high prediction accuracy [95].

Using data on food and beverage sales, Dunstan et al. [96] used the algorithms vector machine, random forest, and extreme gradient boosting to predict the prevalence of obesity across the country. They discovered that baked goods, cheese, and carbonated drinks are the most useful food categories for predicting obesity. A DL model was created by utilizing unaugmented Electronic Health Record (EHR) data from 1 to 3 years before that predicted obesity between the ages of 3 and 20 with 80% accuracy [97]. To determine obesity in fourth grade, Zare et al. [98] used kindergarten-level BMI data, demographic profile including income, poverty level, race and ethnicity, housing, educational, and family structure. They achieved an accuracy of about 87% using logistic regression and an ANNs. All these studies show the application of AI in the field of health care and obesity. The vast potential and usage of AI in healthcare sector can be a beneficial tool for improving the public health.

Other health conditions

AI has showed promise in helping with the diagnosis and treatment of dementia a condition that affects millions of individuals worldwide. To detect early indications of cognitive decline and aid in the earlier diagnosis of dementia, AI algorithms can analyze vast volumes of medical data. Also, certain application of AI, such as predictive modeling, personalized care, and assistive technology, are very much beneficial for dementia patients [99]. AI has shown promising effects in the management, diagnosis, and treatment of cardiovascular disease (CVD). Medical imaging is one of the primary areas where AI is being used in CVD. For example, as echocardiograms, CT scans, and MRI scans can be analyzed by AI-based algorithms to identify abnormalities and aid in the diagnosis of CVD. These systems can also track changes over time and give possible problems early warnings [100]. Also, AI-based health technologies are helping in the prevention and management of CVD. Innovative smartphone applications and sensors are being used to deliver customized interventions for CVD patients which helps in monitoring the lipid profile [101].

AI has the potential to significantly contribute to the management and prevention of metabolic diseases. It is characterized by the cluster of problems, such as Type 2 diabetes, abdominal obesity, and cardiovascular disease. Patients with type 2 diabetes can improve their glycemic control with nutritional intervention. AI-based nutritional intervention are proved to be effective for diabetic patients. For example, patients can use mobile devices to log their daily nutritional intake and speak with dieticians online [102]. Dietary self-monitoring is regarded as an effective tactic for changing behavior on its own. Automatic food item recognition and nutritional value assessment can be done by photo analysis technology; this aids in enhancing glycemic control in type 2 diabetic patients [101]. AI systems may analyze data, including medical records, genetic data, lifestyle factors, and environmental factors, and help in early diagnosis. AI can also contribute to the creation of new treatments and drugs, which can help manage metabolic problems [103]. Table 2 shows the different studies that utilized the AI domain for clinical nutrition and health research.

Challenges of AI

Although AI has demonstrated considerable promise in the fields of nutrition and healthcare, there are still a number of issues and challenges that need to be resolved. Data quality is one of the issues as to train algorithms and produce reliable predictions, AI strongly depends on a vast volume of high-quality data. However, because data are frequently insufficient, inconsistent or inaccurate data quality can be a serious problem in the healthcare and nutrition fields [13]. Healthcare and nutrition are intricate, diverse field with a wide range of potential variables that has an impact on the outcomes. Hence, AI algorithms can find it difficult to make reliable forecasts or suggestions [113]. Healthcare and

Table 2 Various AI domains used for clinical nutrition and health research

Study references	Topic	Domain	Sample	Applications
[104]	Intake of nutrients, such as carbohydrate, protein, and mineral	DL and ML	322 meals pictures and recipes were put together	Estimation by RGB image processing
[105]	Vitamin supplementation	DL	3 public databases	Bioinformatic and network analysis
[106]	Carbohydrate counting for diabetes	DL and ML	54 plated meals with 3 different food items	GoCARB AI-based application estimate carbs of plated meals
[107]	Assessment of dietary intake	DL and ML	214 recall participants	ASAA24 web-based tool for 24-h dietary recall
[108]	Level of trace elements	DL, ML, and ANN	2000 dynamic internal media samples, 750 drinking water sample	Microelement level determination in body
[109]	Parkinson patients' dietary assessment	ANN	520 food and drink items, 100 images each	Image processing tool NutriNet, The final collection consists of 130,517 photographs
[68]	Calorie and macronutrient	DL and ML	2 meal image input	GoFOOD: food image
[110]	Anemia detection	DL and ML	20 pregnant women aged 22–36 year	Camera-based prediction
[111]	Excess body fat percentage	ANN	1999 children aged 8–19 years	Input parameters of age, height, weight, and waist circumference
[112]	Diet assessment	ANN	20,000 pairs of depth images	3D cloud mapping for management of dietary behavior

nutrition require interpersonal connections between healthcare providers and patients, which AI may find challenging to mimic. AI cannot take the role of the human touch, empathy, and emotional support offered by healthcare personnel [114]. The major challenge is not the capability of these applications but rather ensuring the applicability and acceptance of AI-based technologies in daily healthcare practices [10].

AI-based health applications are becoming very popular, with applications ranging from food advice to health evaluations, assistance with medication adherence, and analysis of data gathered by wearable sensors. Such applications raise concern for ethical considerations, sometimes due to lack of time or difficulty in understanding the agreements people ignore them. This can pose a threat to privacy of individuals using these applications [115]. One another main challenge of AI is safety especially in the field of healthcare and nutrition. Patient medical records are analyzed using AI algorithms and assist doctors in providing treatment to patients. However, it has recently been criticized for allegedly making "unsafe and incorrect" recommendations in some circumstances [116]. Some degree of transparency must be guaranteed for the sake of patient's confidence and safety. While practically some amount of information is accessible to the public, there may be some real concerns about safeguarding investments and intellectual property as well as avoiding an increase in cybersecurity risk [117].

The use of AI in food science and nutrition is becoming more widespread, though the extent of this growth depends on particular resources and applications. Open-source libraries, software, AI-based mobile applications and cloud-based platforms are some of the factors increasing the accessibility. The potential offered by these technical developments is enormous, particularly for patients with disability or any serious health condition [118]. However, the accessibility depends on the awareness regarding these technologies, cost, user-friendly nature, and quality. The ethical and legal issues surrounding AI may potentially have an impact on its accessibility. The use and sharing of data may be restricted by compliance with data protection, privacy laws, and ethical standards, which may have an impact on the usability of AI systems. Talking about data protection and individual rights. The development and application of AI technology must take individual rights and data protection into account. Large amounts of data, particularly sensitive personal data, are frequently needed by AI systems to train and enhance their algorithms. To guarantee that data are gathered, stored, and processed in a secure and confidential manner, it is crucial to protect privacy of individuals. To protect individual rights to privacy, it is essential to abide with data protection laws and regulation. Strong governance frameworks should be established by organizations employing AI technologies to this [119].

Proprietary AGI's (Artificial General Intelligence) impact on initiatives that are now under development around the world may vary depending on a number of variables and the unique features of the system. AGI is able of learning and performing cognitive task that humans are capable of. There

are several advantages of which includes automation of difficult task, speeding up the labor-intensive process, helping the disabled and many more. On the other hand, there are a lot of negative impacts, such as misuse by criminals or terrorists, loss of job, unreasonable conflicts, and many more. Prominent leaders such as Elon Musk say AI-based tools and systems should only be developed when we are sure that they will have positive result and causes minimal risks that are manageable [120].

The readers of the paper can get knowledge about various AI-based approaches and tools that are applied in the field of nutrition, healthcare, and food science. It offers insightful information, and findings that can help practitioners and researchers gain a deeper knowledge about this topic. It will also familiarize them with the existing review that includes the basic concept of AI, ML, DL, ANN, IoT, food image recognition, and the application of AI in disease management. It can also provide information on how to apply AI tools, approaches, and applications to handle nutrition-related issues, enhance dietary assessments, and improve personalized nutrition advice. The paper can assist in highlighting research gaps, finding new research questions, and suggest further research investigation.

Research needs and future direction

AI is transforming the field of nutrition, healthcare and food science with emerging, faster, and more digitalized platforms. AI-assisted clinical trials may mark the beginning of a new era. Using the environment, behavioral, and lifestyle data gathered through social media, wearable technology monitoring, and different mobile applications, we can embark an era of AI-assisted personalized medicine and nutrition care. With the help of AI, we can we can speed up the disease diagnostic procedure, customize nutritional needs of patients, provide individual specific treatment and diet, promote self-monitoring, and classify risk factors. Not only this AI works for the betterment of crop production which ultimately leads to high nutritive value crops and products. A large number of software companies as well as academic institutions are working on AI research in healthcare, nutrition, and medicine. Research may be conducted on better understandable model of AI for use in these fields. This includes understanding how AI algorithms generate suggestions, provide reasonable answers, and guarantee AI is used ethically.

The future research on the long-term consequences of AI-based therapies on health outcomes need to be explored. The research on assessment and evaluation of AI-based dietary interventions on a large scale is also needed. The successful and innovative research in this field demands alliances among scientists from diverse areas, such as computer science, food science, nutrition, and data science. The interdisciplinary research by experts in these areas can lead to the development of AI-based innovative technologies, interventions, and applications that can be applied to the field of nutrition and healthcare.

Conclusion

Application of AI-based approaches results in improved data collection, processing, and comprehension of complicated nutrition-related information, as well as advanced assessment of nutritional status. AI will play a significant role in future healthcare options. AI predictive models improves the effects of food on illness outcomes. However, a number of challenges and issues with the use of AI in the field of nutrition and healthcare research highlight the need for additional research to create and identify the best algorithms that can be used be in future. The gaps that still exist between the promises and the true enhancements of research through AI reinforce the need of using AI-based approaches with caution, ethical considerations, and equity. Overall, AI has the potential to significantly advance the medical, clinical nutrition, dietetics, and healthcare field, but it is crucial to approach carefully and make sure that moral considerations are given top priority.

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References

1. Prasad R, Choudhary P. State-of-the-art of artificial intelligence. J Mob Multimedia. 2021;17:427–54.

2. McCarthy J. From here to human-level AI. Artif Intell. 2007;171(18):1174–82.
3. Mondal B. Artificial intelligence: state of the art. In: Balas V, Kumar R, Srivastava R, editors. Recent trends and advances in artificial intelligence and internet of things. Intelligent Systems Reference Library, vol 172. Springer, Cham. https://doi.org/10.1007/978-3-030-32644-9_32
4. Xu Y, Liu X, Cao X, Huang C, Liu E, Qian S, Zhang J. Artificial intelligence: a powerful paradigm for scientific research. Innovation. 2021;2(4): 100179.
5. Zheng ZY, Guo XN, Zhu KX, Peng W, Zhou HM. Artificial neural network- genetic algorithm to optimize wheat germ fermentation condition: application to the production of two anti-tumor benzoquinones. Food Chem. 2017;227:264–70.
6. Sak J, Suchodolska M. Artificial intelligence in nutrients science research: a review. Nutrients. 2021;13(2):322.
7. Morgenstern JD, Rosella LC, Costa AP, De Souza RJ, Anderson LN. Perspective: big data and machine learning could help advance 734 nutritional epidemiology. Adv Nutr. 2021;12:621–31.
8. Mazzei A, Anselma L, De Michieli F, Bolioli A, Casu M, Gerbrandy J, Lunardi I (2015) Mobile computing and artificial intelligence for diet management. In New Trends in Image Analysis and Processing--ICIAP 2015 Workshops: ICIAP 2015 International Workshops, BioFor, CTMR, RHEUMA, ISCA, MADiMa, SBMI, and QoEM, Genoa, Italy, September 7–8, 2015, Proceedings 18. Springer International Publishing; p. 342–349.
9. Subramanian M, Wojtusciszyn A, Favre L, Boughorbel S, Shan J, Letaief KB, Chouchane L. Precision medicine in the era of artificial intelligence: implications in chronic disease management. J Transl Med. 2020;18(1):1–12.
10. Davenport T, Kalakota R. The potential for artificial intelligence in healthcare. Future Healthc J. 2019;6(2):94.
11. Singh J, Singh N, Fouda MM, Saba L, Suri JS. Attention-enabled ensemble deep learning models and their validation for depression detection: a domain adoption paradigm. Diagnostics. 2023;13(12):2092.
12. Dubey AK, Chabert GL, Carriero A, Pasche A, Danna PS, Agarwal S, Suri JS. Ensemble deep learning derived from transfer learning for classification of COVID-19 patients on hybrid deep-learning-based lung segmentation: a data augmentation and balancing framework. Diagnostics. 2023;13(11):1954.
13. Côté M, Lamarche B. Artificial intelligence in nutrition research: perspectives on current and future applications. Appl Physiol Nutr Metab. 2022;47(1):1–8.
14. Pesapane F, Codari M, Sardanelli F. Artificial intelligence in medical imaging: threat or opportunity? Radiologists again at the forefront of innovation in medicine. Eur Radiol Exp. 2018;2:35.
15. Sharma N, Sharma R, Jindal N. Machine learning and deep learning applications-a vision. Glob Transit Proc. 2021;2(1):24–8.
16. Demirci F, Akan P, Kume T, Sisman AR, Erbayraktar Z, Sevinc S. Artificial neural network approach in laboratory test reporting: learning algorithms. Am J Clin Pathol. 2016;146:227–37.
17. Janiesch C, Zschech P, Heinrich K. Machine learning and deep learning. Electron Mark. 2021;31(3):685–95.
18. Gallucci M, Pallucca C, Di Battista ME, Fougère B, Grossi E, Fougèreand B. Artificial neural networks help to better understand the interplay between cognition, mediterranean diet, and physical performance: clues from TRELONG study. J Alzheimer's Dis. 2019;71:1321–30.
19. Thara L. Gastric cancer prediction: a comparative analysis of methodologies and performances in deep learning perspective. J Gujarat Res Soc. 2019;21:147–53.
20. Kather JN, Pearson AT, Halama N, Jäger D, Krause J, Loosen SH, et al. Deep learning can predict microsatellite instability directly from histology in gastrointestinal cancer. Nat Med. 2019;25:1054–6.
21. Mao WB, Lyu JY, Vaishnani DK, Lyu YM, Gong W, Xue XL, et al. Application of artificial neural networks in detection and diagnosis of gastrointestinal and liver tumors. World J Clin Cases. 2020;8(18):3971.
22. Hafiz R, Haque MR, Rakshit A, Uddin MS. Image-based soft drink type classification and dietary assessment system using deep convolutional neural network with transfer learning. J King Saud Univ Comp. 2022;34(5):1775–84.
23. Brous P, Janssen M, Herder P. The dual effects of the internet of things (IoT): a systematic review of the benefits and risks of IoT adoption by organizations. Int J Inf Manage. 2020;51: 101952.
24. AL Mogbil R, AL Asqah M, EL Khediri S (2020) Iot: security challenges and issues of smart homes/cities. In: 2020 International Conference on Computing and Information Technology (ICCIT-1441). IEEE; p. 1–6.
25. Jæger B, Mishra A. IoT platform for seafood farmers and consumers. Sensors. 2020;20(15):4230.
26. Suganyadevi S, Shamia D, Balasamy K (2022) An IoT-based diet monitoring healthcare system for women. Smart healthcare system design: security and privacy aspects. p. 167–202.
27. Hrushikesava Raju S, Thrilok SS, Reddy KPSK, Karthikeya G, Kumar MT. An IoT vision for dietary monitoring system and for health recommendations. In: Inventive communication and computational technologies: Proceedings of ICICCT. Singapore: Springer Singapore;z 2022.
28. Suhag S, Singh N, Jadaun S, Johri P, Shukla A, Parashar N (2021). IoT based soil nutrition and plant disease detection system for smart agriculture. In 2021 10th IEEE International Conference on Communication Systems and Network Technologies (CSNT), IEEE, p. 478–483.
29. Pal A. Smart Health: automated nutrition monitoring management system in the IoT. Annals of the Romanian Society for Cell Biology. 2019;23(2):212–26.
30. Fleisch E (2010) What is the internet of things. When things add value. Auto-ID labs white paper WP-BIZAPP-053, Auto-ID Lab St. Gallen, Switzerland, 1.
31. Limketkai BN, Mauldin K, Manitius N, Jalilian L, Salonen BR. The age of artificial intelligence: use of digital technology in clinical nutrition. Curr Surg Rep. 2021;9(7):20.
32. Smith C, Karunaratne S, Badenhorst P, Cogan N, Spangenberg G, Smith K. Machine learning algorithms to predict forage nutritive value of in situ perennial ryegrass plants using hyperspectral canopy reflectance data. Remote Sens. 2020;12(6):928.
33. Sadhu T, Banerjee I, Lahiri SK, Chakrabarty J. Enhancement of nutritional value of fried fish using an artificial intelligence approach. Environmental Science and Pollution Research. 2021;29:20048–63.
34. Kleineidam J. Fields of action for designing measures to avoid food losses in logistics networks. Sustainability. 2020;12:6093.
35. How ML, Chan YJ, Cheah SM. Predictive insights for improving the resilience of global food security using artificial intelligence. Sustainability. 2020;12(15):6272.
36. Bansal S, Singh A, Mangal M, Mangal AK, Kumar S. Food adulteration: sources, health risks, and detection methods. Crit Rev Food Sci Nutr. 2017;57(6):1174–89.
37. Goyal K, Kumar P, Verma K. Food adulteration detection using artificial intelligence: a systematic review. Arch Computat Methods Eng. 2022;29(1):397–426.
38. Kao CK, Liebovitz DM. Consumer mobile health apps: current state, barriers, and future directions. Phy Medi Rehab. 2017;9(5S):S106–15.
39. Flores MG, Granado-Font E, Ferre'-Grau C, Montan˜a-Carreras X. Mobile phone apps to promote weight loss and increase

physical activity: a systematic review and meta-analysis. J Med Internet Res. 2015;17(11):253.
40. Tschandl P, Rinner C, Apalla Z, Argenziano G, Codella N, Halpern A, et al. Human-computer collaboration for skin cancer recognition. Nat Med. 2020;26(8):1229–34.
41. Byrne MF, Chapados N, Soudan F, Oertel C, Linares Perez M, Kelly R, et al. Real-time differentiation of adenomatous and hyperplastic diminutive colorectal polyps during analysis of unaltered videos of standard colonoscopy using a deep learning model. Gut. 2019;68(1):94–100.
42. Masset G, Monsivais P, Maillot M, Darmon N, Drewnowski A. Diet optimization methods can help translate dietary guidelines into a cancer prevention food plan. J Nutr. 2009;139(8):1541–8.
43. Rigdon J, Basu S. Machine learning with sparse nutrition data to improve cardiovascular mortality risk prediction in the USA using nationally randomly sampled data. Bio Med J Open. 2019;9(11): 032703.
44. Dias R, Torkamani A. Artificial intelligence in clinical and genomic diagnostics. Genome med. 2019;11(1):1–12.
45. Retson TA, Besser AH, Sall S, Golden D, Hsiao A. Machine learning and deep neural networks in thoracic and cardiovascular imaging. J Thorac Imaging. 2019;34:192–201.
46. Gulshan V, Peng L, Coram M, Stumpe MC, Wu D, Narayanaswamy A, et al. Development and validation of a deep learning algorithm for detection of diabetic retinopathy in retinal fundus photographs. J Am Med Assoc. 2016;316:2402–10.
47. Lee C, Kim S, Kim J, Lim C, Jung M. Challenges of diet planning for children using artificial intelligence. Nutr Res Pract. 2022;16(6):801–12.
48. Mortazavi BJ, Gutierrez-Osuna R. A review of digital innovations for diet monitoring and precision nutrition. J Diabetes Sci Technol. 2023;17(1):217–23.
49. Epstein DA, Cordeiro F, Fogarty J, Hsieh G, Munson SA (2016) Crumbs: lightweight daily food challenges to promote engagement and mindfulness. In: Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems. p. 5632–5644.
50. Bell BM, Alam R, Alshurafa N, Thomaz E, Mondol AS, de la Haye K, et al. Automatic, wearable-based, in-field eating detection approaches for public health research: a scoping review. NPJ Digit Med. 2020;3(1):38.
51. MyFitnessPal https://www.myfitnesspal.com/. Accessed 5 Mar 2023.
52. Cordeiro F, Bales E, Cherry E, Fogarty J (2015) Rethinking the mobile food journal: Exploring opportunities for lightweight photo-based capture. In: Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems. p. 3207–3216.
53. Zepeda L, Deal D. Think before you eat: photographic food diaries as intervention tools to change dietary decision making and attitudes. Int J Consum Stud. 2008;32(6):692–8.
54. Owens SJ (2023) The 8 best food tracker apps of 2023 The 8 Best Food Tracker Apps of 2023 (lifewire.com). Accessed 3 Jan 2023.
55. Ciocca G, Napoletano P, Schettini R. Food recognition: a new dataset, experiments, and results. IEEE J Biomed Health Inform. 2017;21(3):588–98.
56. Dalakleidi KV, Papadelli M, Kapolos I, Papadimitriou K. Applying image-based food-recognition systems on dietary assessment: a systematic review. Adv Nutr. 2022;13(6):2590–619.
57. Vasiloglou MF, Christodoulidis S, Reber E, Stathopoulou T, Lu Y, Stanga Z, et al. What healthcare professionals think of "nutrition & diet" apps: an international survey. Nutrients. 2020;12(8):2214.
58. Huang Q, Yang Z, Zhang Q (2018) Smart-U: smart utensils know what you eat. In: IEEE INFOCOM 2018-IEEE Conference on Computer Communications, Honolulu, HI, 16–19 April IEEE; p. 1439–1447.
59. Hedrick VE, Dietrich AM, Estabrooks PA, Savla J, Serrano E, Davy BM. Dietary biomarkers: advances, limitations and future directions. Nutr J. 2012;11(1):109.
60. Afreen S, Zhu JJ. Rethinking EBAD: evolution of smart noninvasive detection of diabetes. TrAC Trends Anal Chem. 2019;118:477–87.
61. Fakoor R, Ladhak F, Nazi, Huber M (2019) Using deep learning to enhance cancer diagnosis and classification. In: Proceedings of the International Conference on Machine Learning 28:3937-3949.
62. Vial A, Stirling D, Field M, et al. The role of deep learning and radiomic feature extraction in cancer-specific predictive modelling: a review. Transl Cancer Res. 2018;7:803–16.
63. Hussain A, Malik A, Halim MU, Ali AM. The use of robotics in surgery: a review. Int J Clin Pract. 2014;68:1376–82.
64. Hosny A, Parmar C, Quackenbush J, Schwartz LH, Aerts HJ. Artificial intelligence in radiology. Nat Rev Cancer. 2018;18(8):500–10.
65. Karakülah G, Dicle O, Koşaner Ö, Suner A, Birant ÇC, Berber T et al (2014) Computer based extraction of phenoptypic features of human congenital anomalies from the digital literature with natural language processing techniques. e-Health-For Continuity of Care. 205: 570–574.
66. Connelly TM, Malik Z, Sehgal R, Byrnes G, Cofey JC, Peirce C. The 100 most influential manuscripts in robotic surgery: a bibliometric analysis. J Robot Surg. 2020;14(1):155–65.
67. Jiang F, Jiang Y, Zhi H, Dong Y, Li H, Ma S, Wang Y. Artificial intelligence in healthcare: past, present and future. Stroke Vascu Neurol. 2017;2(4):230–43.
68. Lu Y, Stathopoulou T, Vasiloglou MF, Pinault LF, Kiley C, Spanakis EK, et al. goFOODTM: an artificial intelligence system for dietary assessment. Sensors. 2020;20(15):4283.
69. Manogaran G, Shakeel PM, Fouad H, Nam Y, Baskar S, Chilamkurti N, Sundarasekar R. Wearable IoT smart-log patch: an edge computing-based Bayesian deep learning network system for multi access physical monitoring system. Sensors. 2019;19(13):3030.
70. Meskò B, Drobni Z, Bényei E, Gergely B, Gyorfy Z. Digital health is a cultural transformation of traditional healthcare. Mhealth. 2017;3:38.
71. Shaheen MY. Applications of Artificial Intelligence (AI) in healthcare: a review. Science Open Preprints. 2021; 1–8. https://doi.org/10.14293/S2199-1006.1.SOR-.PPVRY8K.v1
72. Chatterjee A, Gerdes MW, Martinez SG. Identification of risk factors associated with obesity and overweight- a machine learning overview. Sensors. 2020;20(9):2734.
73. Pouladzadeh P, Kuhad P, Peddi SVB, Yassine A, Shirmohammadi S (2016) Food calorie measurement using deep learning neural network. In Proceedings of the 2016 IEEE International Instrumentation and Measurement Technology Conference, Taipei, Taiwan 23–26 May 2016:1–6.
74. Kolker E, Özdemir V, Kolker E. How healthcare can refocus on its super-customers (patients, n=1) and customers (doctors and nurses) by leveraging lessons from Amazon, Uber, And Watson. OMICS. 2016;20(6):329–33.
75. Rigby MJ. Ethical dimensions of using artificial intelligence in health care. AMA J Ethics. 2019;21(2):121–4.
76. Yang X, Wang Y, Byrne R, Schneider G, Yang S. Concepts of artifcial intelligence for computer-assisted drug discovery | chemical reviews. Chem Rev. 2019;119(18):10520–94.
77. England JR, Cheng PM. Artificial intelligence for medical image analysis: a guide for authors and reviewers. Am J Roentgenol. 2019;212(3):513–9.
78. Peng J, Jury EC, Dönnes P, Ciurtin C. Machine learning techniques for personalised medicine approaches in

immune-mediated chronic inflammatory diseases: applications and challenges. Front Pharmacol. 2021;12: 720694.
79. Fleming N. How artificial intelligence is changing drug discovery. Nature. 2018;557(7706):S55–S55.
80. Balthazar P, Harri P, Prater A, Safdar NM. Protecting your patients' interests in the era of big data, artificial intelligence, and predictive analytics. J Am Coll Radiol. 2018;15(3):580–6.
81. Tian S, Yang W, Le Grange JM, Wang P, Huang W, Ye Z. Smart healthcare: making medical care more intelligent. Globl Health J. 2019;3(3):62–5.
82. Greer S, Ramo D, Chang Y-J, Michael Fu, Moskowitz J, Haritatos J. Use of the chatbot "Vivibot" to deliver positive psychology skills and promote well-being among young people after cancer treatment: randomized controlled feasibility trial. J Med Int R mHealth uHealth. 2019;7(10):15018.
83. Rincon E, Monteiro-Guerra F, Rivera-Romero O, Dorronzoro-Zubiete E, Sanchez-Bocanegra CL, Gabarron E. Mobile phone apps for quality of life and well-being assessment in breast and prostate cancer patients: systematic review. J Med Internet Res. 2017;5(12):8741.
84. Qiu L, Kanski B, Doerksen S, Winkels R, Schmitz KH, Abdullah S (2021) Nurse amie: Using smart speakers to provide supportive care intervention for women with metastatic breast cancer. In: Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems. p. 1–7.
85. Gordon BR, Qiu L, Doerksen SE, Kanski B, Lorenzo A, Truica CI, Schmitz KH. Addressing metastatic individuals everyday: rationale and design of the nurse AMIE for amazon echo show trial among metastatic breast cancer patients. Contemp Clin Trials. 2023;32:101058.
86. Schmitz KH, Schleicher E, Doerksen S, Truica C, Cream L, Kass HM. Testing the acceptability and feasibility of a tablet-based supportive cancer platform for patients with metastatic breast cancer. J Cancer Surviv. 2021;15:410–3.
87. Chung H, Ko Y, Lee IS, Hur H, Huh J, Han SU, et al. Prognostic artificial intelligence model to predict 5 year survival at 1 year after gastric cancer surgery based on nutrition and body morphometry. J Cachexia Sarcopenia Muscle. 2023;14:847–59.
88. Ko Y, Shin H, Shin J, Hur H, Huh J, Park T, et al. Artificial Intelligence mortality prediction model for gastric cancer surgery based on body morphometry, nutritional, and surgical information: feasibility study. Appl Sci. 2022;12:3873.
89. Gauthier G, Gagnon-Sanschagrin P, Guérin A, Burne R, Small T, Niravath P, Dalal AA. Economic burden of HR+/HER2-metastatic breast cancer among adult premenopausal women. Adv ther. 2018;35:503–14.
90. Fox R, Bui Y (2015) An artificial intelligence approach to nutritional meal planning for cancer patients. In Artificial Intelligence Perspectives and Applications: Proceedings of the 4th Computer Science On-line Conference 2015 (CSOC2015), Vol 1: Artificial Intelligence Perspectives and Applications; p. 215–224.
91. Colmenarejo G. Machine learning models to predict childhood and adolescent obesity: a review. Nutrients. 2020;12(8):2466.
92. Safaei M, Sundararajan EA, Driss M, Boulila W, Shapi'I AA. Systematic literature review on obesity: understanding the causes & consequences of obesity and reviewing various machine learning approaches used to predict obesity. Comput Biol Med. 2021;136:104754.
93. Butler ÉM, Derraik JG, Taylor RW, Cutfield WS. Childhood obesity: how long should we wait to predict weight? J Pediatr Endocrinol Metab. 2018;31:497–501.
94. Queally M, Doherty E, Matvienko-Sikar K, Toomey E, Cullinan J, Harrington JM, et al. Do mothers accurately identify their child's overweight/obesity status during early childhood? Evidence from a nationally representative cohort study. Int J Behav Nutr Phys Act. 2018;15:56.
95. Alotaibi M, Alnajjar F, Cappuccio M, Khalid S, Alhmiedat Tpra, Mubin O. Efficacy of emerging technologies to manage childhood obesity. Diabetes Metab Syndr Obes Targets Ther.2022;15:1227–44.
96. Dunstan J, Aguirre M, Bastías M, Nau C, Glass TA, Tobar F. Predicting nationwide obesity from food sales using machine learning. Health Inform J. 2020;26:652–63.
97. Gupta M, Phan TLT, Bunnell HT, Beheshti R. Obesity Prediction with EHR Data: a deep learning approach with interpretable elements. ACM Trans Comput Healthc. 2022;3(3):1–19.
98. Zare S, Thomsen MR, Nayga RM Jr, Goudie A. Use of machine learning to determine the information value of a BMI screening program. Am J Prev Med. 2021;60:425–33.
99. Vinay R, Biller-Andorno N. A critical analysis of national dementia care guidances. Health Pol. 2023;130:104736.
100. Yan Y, Zhang JW, Zang GY, Pu J. The primary use of artificial intelligence in cardiovascular diseases: what kind of potential role does artificial intelligence play in future medicine? J Geriar Cardiol. 2019;16(8):585.
101. Oka R, Nomura A, Yasugi A, Kometani M, Gondoh Y, Yoshimura K, Yoneda T. Study protocol for the effects of artificial intelligence (AI)-supported automated nutritional intervention on glycemic control in patients with type 2 diabetes mellitus. Diabetes Ther. 2019;10:1151–61.
102. Grock S, Ku JH, Kim J, Moin T. A review of technology-assisted interventions for diabetes prevention. Curr Diab Rep. 2017;17:107.
103. Dankwa-Mullan I, Rivo M, Sepulveda M, Park Y, Snowdon J, Rhee K. Transforming diabetes care through artificial intelligence: the future is here. Popul Health Manag. 2019;22(3):229–42.
104. Lu Y, Stathopoulou T, Vasiloglou MF, Christodoulidis S, Blum B, Walser T, Meier V, Stanga Z, Mougiakakou SG. An artificial intelligence-based system for nutrient intake assessment of hospitalised patients. Annu Int Conf IEEE Eng Med Biol Soc. 2019;2019:5696–99.
105. Chen L, Hu C, Hood M, Zhang X, Zhang L, Kan J, Du J. A novel combination of vitamin C, curcumin and glycyrrhizic acid potentially regulates immune and inflammatory response associated with coronavirus infections: a perspective from system biology analysis. Nutrients. 2020;12:1193.
106. Vasiloglou MF, Mougiakakou S, Aubry E, Bokelmann A, Fricker R, Gomes F, Guntermann C, Meyer AL, Studerus D, Stanga Z. A Comparative study on carbohydrate estimation: GoCARB vs. dietitians. Nutrients. 2018;10:741.
107. Chin EL, Simmons G, Bouzid YY, Kan A, Burnett DJ, Tagkopoulos I, Lemay DG. Nutrient estimation from 24-hour food recalls using machine learning and database mapping: a case study with lactose. Nutrients. 2019;11:3045.
108. Tunakova Y, Novikova S, Ragimov A, Faizullin R, Valiev V. A Method for assessing the retention of trace elements in human body using neural network technology. J Heal Eng. 2017. https://doi.org/10.1155/2017/3471616.
109. Mezgec S, Koroušić SB. NutriNet: a deep learning food and drink image recognition system for dietary assessment. Nutrients. 2017;9:657.
110. Anggraeni MD, Fatoni A. Non-invasive self-care anemia detection during pregnancy using a smartphone camera. In: IOP Conference series: materials science and engineering, vol. 72. Bristol: IOP Publishing; 2017. p. 012030.
111. Duran I, Martakis K, Rehberg M, Semler O, Schoenau E. Diagnostic performance of an artificial neural network to predict excess body fat in children. Pediatr Obes. 2019. https://doi.org/10.1111/ijpo.12494.

112. Lo FPW, Sun Y, Qiu J, Lo B. Food volume estimation based on deep learning view synthesis from a single depth map. Nutrients. 2018;10:2005.
113. Zhao X, Xu X, Li X, He X, Yang Y, Zhu S. Emerging trends of technology-based dietary assessment: a perspective study. Eur J Clin Nutr. 2021;75(4):582–7.
114. Matheny ME, Whicher D, Thadaney Israni S. Artificial intelligence in 690 health care: a report from the national academy of medicine. J Am Med Assoc. 2020;323:509–10.
115. Gerke S, Minssen T, Yu H, Cohen IG. Ethical and legal issues of ingestible electronic sensors. Nat Electron. 2019;2(8):329–34.
116. Cohen IG, Amarasingham R, Shah A, Xie B, Lo B. The legal and ethical concerns that arise from using complex predictive analytismithcs in health care. Health Aff. 2014;33(7):1139–47.
117. Gerke S, Minssen T, Cohen G. Ethical and legal challenges of artificial intelligence-driven healthcare. In: Artificial intelligence in healthcare. Cambridge: Academic Press; 2020. p. 295–336.
118. Abou-Zahra S, Brewer J, Cooper M (2018) Artificial intelligence (AI) for web accessibility: Is conformance evaluation a way forward? In: Proceedings of the 15th International Web for All Conference; p. 1–4.
119. Mitrou L. Data protection, artificial intelligence and cognitive services: is the general data protection regulation (GDPR) 'artificial intelligence-proof'? Artificial intelligence and cognitive services: is the general data protection regulation (GDPR) artificial intelligence-proof. SSRN J. 2018. https://doi.org/10.2139/ssrn.3386914.
120. Artificial general intelligence https://www.chidiameke.com/post/exploring-the-future-of-ai-agi-ethical-development-benefits-and-risks. Accessed 15 Mar 2023.