Review article

DIGITAL HEALTH
Volume 9: 1–15

DOI: 10.1177/20552076231189331
journals.sagepub.com/home/dhj
Sage

Application of artificial intelligence in medical technologies: A systematic review of main trends

Olga Vl Bitkina[1], **Jaehyun Park**[1] and **Hyun K. Kim**[2]

Abstract

Objective: Artificial intelligence (AI) has been increasingly applied in various fields of science and technology. In line with the current research, medicine involves an increasing number of artificial intelligence technologies. The introduction of rapid AI can lead to positive and negative effects. This is a multilateral analytical literature review aimed at identifying the main branches and trends in the use of using artificial intelligence in medical technologies.

Methods: The total number of literature sources reviewed is n = 89, and they are analyzed based on the literature reporting evidence-based guideline PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) for a systematic review.

Results: As a result, from the initially selected 198 references, 155 references were obtained from the databases and the remaining 43 sources were found on open internet as direct links to publications. Finally, 89 literature sources were evaluated after exclusion of unsuitable references based on the duplicated and generalized information without focusing on the users.

Conclusions: This article is identifying the current state of artificial intelligence in medicine and prospects for future use. The findings of this review will be useful for healthcare and AI professionals for improving the circulation and use of medical AI from design to implementation stage.

Keywords

Artificial intelligence, eHealth, machine learning, medical technologies, medical apps

Submission date: 20 December 2022; Acceptance date: 30 June 2023

Introduction

General state of AI in medicine

Medical technologies play a vital role in the treatment and diagnosis of patients because of their direct contact with users (doctors, medical staff, and patients). According to the official site of Asia Pacific Medical Technology Association 'APACMed'[1]: 'Medical Technologies are technologies that diagnose, treat and/or improve a person's health and wellbeing'. The introduction of artificial intelligence (AI) into medical technologies is becoming one of the important stages of their design and development.[2–11] The main areas of medical AI application include imaging processing, physiological signal recognition, and neurological health issues.[12–15] Deep medicine (DM) is the definition of medicine involving AI applications to acquire, process, and analyze medical and clinical data (Watson, 2019). DM includes the development and use of machine learning algorithms, apps, and software, which are important medical AI elements.[16–19] The main issue with AI

[1]Department of Industrial and Management Engineering, Incheon National University, Incheon, Korea
[2]School of Information Convergence, Kwangwoon University, Seoul, Korea

Corresponding author:
Jaehyun Park, Department of Industrial and Management Engineering, Incheon National University, Incheon, Korea.
Email: jaehpark@inu.ac.kr

introduction in healthcare is users' trust in this type of technology because the medical function performance or the processing of information by the device is invisible to doctors, medical staff, and patients.[20] The importance of this trust is due to the fact that the user is passing a function to the AI that he cannot perform on his own, and therefore does not fully understand the process. Moreover, most AI systems have the function of self-learning and modification of work algorithms. Accordingly, the process cannot be completely transparent and this interaction needs the trust of the users. This implies that the acceptance of AI medical devices by users is based mainly on trust.[21] Lack of trust in users can interfere with the use of AI-based medical devices such as emotional discomfort, increased anxiety, reduced frequency or duration of AI device use, and, in some cases, device abandonment.[21] Thus, participants in the development, production, and sales of the healthcare market are also interested in the implementation of AI technologies and solving the basic problem of mistrust. The main points of AI fear/mistrust in healthcare with the proposed solutions are as follows (Table 1, Revised from[22]):

Table 1. AI issues with possible solutions.

AI Issue	Solution
Validation process of potentially accepted AI for clinical practice	Verification of the AI technology preparation process with subsequent checks, testing, and validation in different medical areas
Joint integration of existing medical devices and new AI	New AI app design for improvement of existing MD operation, data collection, and easy connection with new AI systems
Application of high-quality data sets designed to integrate and maintain the AI operation	Facilitate access to all types of health data to simplify the design
Collection of large-scale data without missing	Collection of all possible types of data – from directly about health to statistical and other remotely related to healthcare
Extension of healthcare areas for AI application	Increase the competitiveness of AI technologies and promote AI more actively in media
Determination of AI limitations in healthcare	Application of various methods to neutralize misunderstandings and misinformation about AI technologies among potential users

Table 1 shows the important challenges and issues for medical AI introduction and the application of medical AI, which can cause mistrust in AI technologies. Solutions to these issues are mostly related to working with users by promoting a better understanding of AI operations, making AI work more transparent, destroying negative myths, and improving the image of AI via education. Additionally, AI developers and designers should be more user-centric to ensure ease in working with AI technologies as well as in reducing the training time and improving user experience. Perception and trust issues have been examined and found to be important in medical AI.[23–26]

In this study, we provide a systematic analytical literature review regarding the trends, benefits, and disadvantages of AI applications from the user point of view over the past three decades. In this study, we aim to assess different areas of AI application in healthcare such as big data, data mining, deep medicine, and clinical imaging. The findings will be useful for healthcare professionals, AI engineers, AI developers, AI providers, and medical and AI researchers to improve the circulation and use of medical AI at all stages of its life cycle from design to implementation.

Research novelty

The presented article is a review dedicated to the summation of previous research on the application of AI in medicine based on PRISMA guidelines. The review of the literature on this topic was carried out by the authors for the first time and demonstrates their first study with the most complete inclusion of literary sources. Evaluation of previous literature allowed to detect the following gaps in presented research topic: lack of coverage of the general state of medical AI over the past decades, limited application of medical AI to a few areas, such as machine and deep learning, lack of overview of the prospects in the field of medical AI, and limited research methods. Based on these research gaps, the study proposed the following novelty which addressing the posed scientific question:

- The article focuses on the general state of artificial intelligence in medicine and paints a broad picture of the problems.
- The main medical applications of artificial intelligence have been identified and gives an understanding of which of them require more implementation of AI technologies;
- The problems and challenges of using AI in medicine have been fully described. The study also focused on issues that are rare in the current literature, such as the ethical and legal regulation of the use of AI in medicine. And this question is scientifically sensitive and

important, since it is directly related to the health and life of patients.
- Based on the described novelty of the study, it can be concluded that the literature review reflects the research question posed about assessing the general state and trends in the application of AI in medicine

Comprehensive literature review

Review method

The present study is a systematic analytical review of the literature concerning the advantages, disadvantages, and dangers of AI medical devices for users. A literature review was performed to evaluate problems arising during the use of AI medical devices from the viewpoint of user perception based on the most current data. Literature analysis was conducted based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. According to the official PRISMA website, PRISMA proposes a minimal set of requirements for systematic reviews and meta-analyses for conducting a literature review of higher quality. PRISMA is universal and can evaluate innovations, contributions, and, sometimes, impact of the reviewed publications.[27] The main principles and sequence of the analysis applied in this study are shown in Figure 1.

International and interdisciplinary literature was selected from 198 sources, without bias, from different databases. The following keywords in different combinations were used during searching process: artificial intelligence, AI, medicine, medical, machine learning, deep learning, medical device, future, challenge, trends, robots, and treatment. From the selected 198 references, 155 references were obtained from the following databases: ScienceDirect, Scopus, PubMed, Google Scholar, SAGE, and PsycINFO. The remaining 43 sources were found on open internet as direct links to publications. Among all the literature sources, 34 sources were duplicates or had similar information. Hence, they were removed, and a subsequent initial abstract review was conducted on 164 publications. After evaluating abstracts and selecting relevant content, 122 literature sources were selected for a full-text review. Next, 33 references were excluded based on the following reasons: generalized information about new AI technologies without focusing on the users, a description of the AI technology design process without considering the impact on the potential user, and the study of non-medical AI devices. The aforementioned literature source evaluation was based on research topics, publication period, theoretical background, findings, and conclusions. During screening, the following keywords and their combinations were used: artificial intelligence, AI, medicine, healthcare, medical devices, user experience, ergonomics, human factors, AI technologies, and AI applications. This literature review approach has been used in different studies on the application of AI technologies, including healthcare. An affirmative answer to the following questions was the main factor that led to the inclusion of the literature sources in the review.

Does the study provide information or findings related to AI in medicine and its impact on users? Does the study discuss the dangers, advantages, and disadvantages of AI applications in medicine? Does this study present methods for the development of AI applications in medicine and healthcare? Does the study provide topics for discussion regarding the dangers, advantages, and disadvantages of AI in medicine and healthcare, considering user experience?

Basic statistics of selected literature

Selected literature sources, using the PRISMA method (published from January 2011 to June 2021), analyzed statistically and showed that the majority of research in the examined field was performed in the USA, Canada, and the UK (Figure 2). In general, active studies connecting AI applications, healthcare, and ergonomics have been performed in a small number of countries. Furthermore, given that only studies till the middle of 2021 were considered, the number of articles has rapidly increased since 2011 (Figure 3). The main areas of AI application in medicine are shown in Figure 4.

Table 2 shows official medical definitions of main AI application areas from Figure 4 accepted for current research.[28–30]

Statistical analysis of the selected literature sources presented above shows that AI in medical devices and technologies is relatively undeveloped. Accelerated growth in the number of studies on these topics started approximately five years ago. The USA, Canada, and the UK are leaders in this research topic. In developing countries, attention to medical AI is much lower than in developed countries.

Overview of artificial intelligence application in medical technologies

In the above sections, it was found that the main branches of medicine using AI are oncology, pulmonology, cardiovascular medicine, orthopedics, hepatology, and neurology. Therefore, it is necessary to analyze and determine the application of AI in these medical areas. Previous studies[31–39] reported the main application of AI in medicine. It was observed that application areas can be classified into three major groups by functionality: collection of medical data, medical data analysis (disease analysis), and active treatment processes (Figure 5).

These three groups are united in the general process of AI application in medicine and treatment, but include different medical activities. The above studies showed that

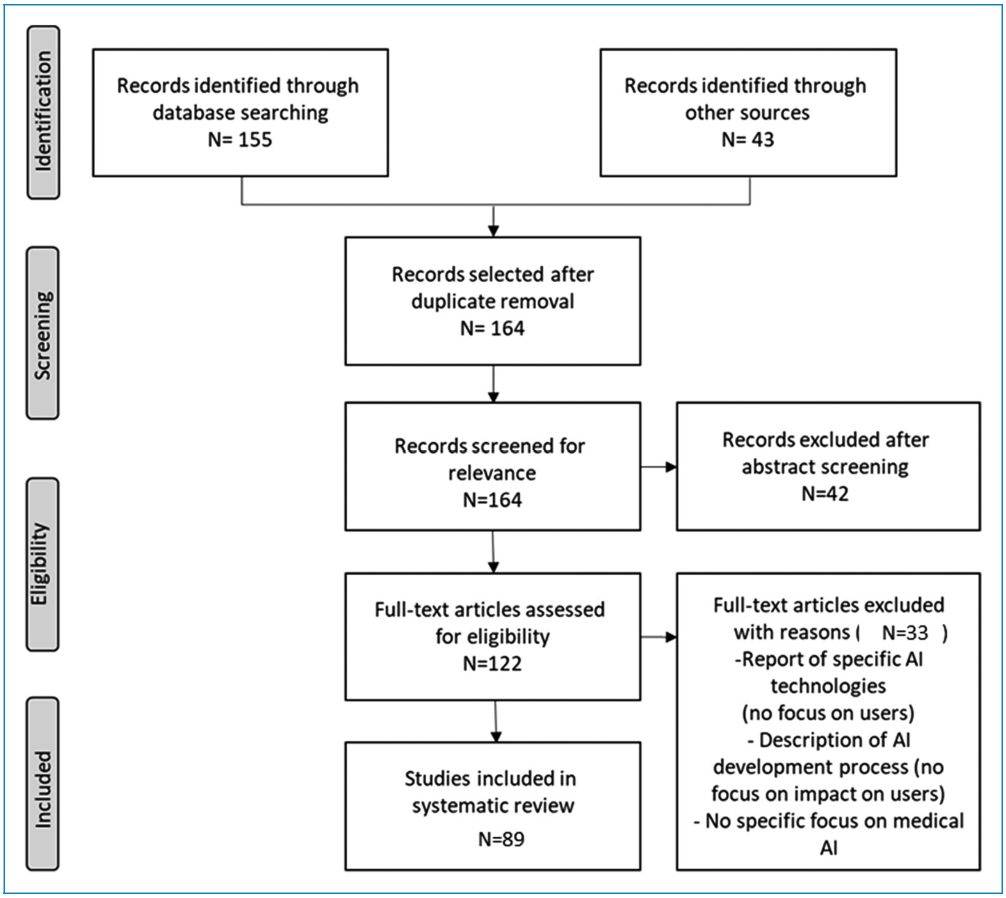

Figure 1. Literature selection for review process according to PRISMA guideline.

the collection stage includes medical data detection and extraction, which is related to the preparation for disease diagnosis. The analysis stage includes the classification and identification of information obtained from the collection stage, which is related to disease/disorder diagnostic activity. The active treatment stage refers to all therapeutic measures considered by the doctor after the diagnosis of the disease/disorder, such as physiotherapy, radiotherapy, surgery, chemotherapy with medication prescription, and prediction and prognosis of the patient state. Previous studies have shown that medical imaging (process of imaging the patient body and separating internal organs before the active treatment process), data exchange, and big data processing are the main applications of each general treatment process stage as shown in Figure 5.[32,33,36] This fact is explained by the idea that working with medical information and visualization plays a significant role in the diagnosis and, therefore, the accuracy and effectiveness of treatment. Active treatment process AI application (from Figure 5) was extracted as one of the main previous literature topics and Table 3 discusses this in more detail.

A brief overview of the studies summarized in Table 3 and Figure 5 shows the following results. Hosny et al.[40] discussed image recognition tasks and visualization methods in radiology, which is a common approach in oncology treatment. The authors discuss the application and future of imaging methods in radiology. Luo et al.[41] introduced a gastrointestinal AI diagnostic system for patients with upper gastrointestinal cancer. Clinical endoscopy imaging data were used to develop this method with high diagnostic accuracy. The basis of this method corresponds to deep learning for medical imaging. The developed AI model is comparable to that of experienced medical professionals in terms of the effectiveness of cancer detection. These studies show that in cancer treatment processes, AI approaches can be equal to those of experienced professionals in data processing and imaging stages. Deep learning approaches have been found to be the most promising and have been implemented in image recognition.[42] Methods, such as convolutional neural networks or variational autoencoders, present a promising future in radiology and oncology. Ardila et al.[43] proposed a method based on a deep learning algorithm in the computed

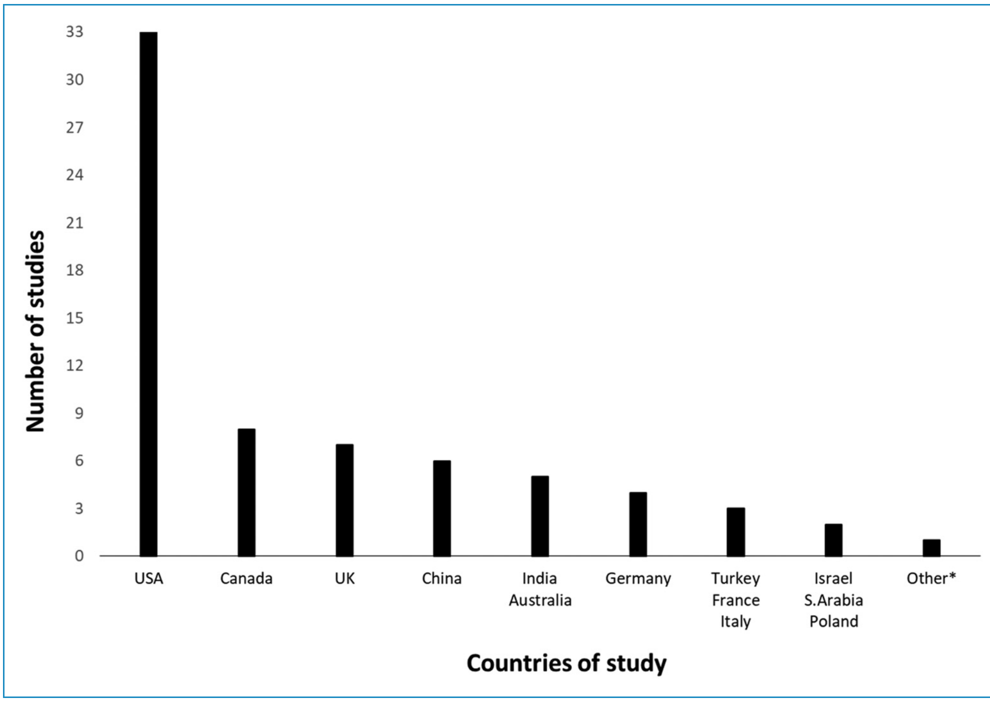

Figure 2. Trend of studies on AI in healthcare and medical devices by country (January 2011–June 2021). * Brazil, Indonesia, Taiwan, Switzerland, New Zealand, Ukraine, Russia, Denmark, Belgium, Portugal, Finland, Malta, and Singapore.

tomography to predict lung cancer. This method shows high accuracy and supports the hypothesis that optimization of the cancer screening process can be performed via introduction of AI. Deep learning methods play an important role in lung cancer screening and increase the accuracy and effectiveness of treatment. Li et al.[44] studied deep convolutional neural network (DCNN) models to improve the ultrasound detection process for thyroid cancer. A highly accurate DCNN model was developed using ultrasound images of patients with cancer. The effectiveness of the model for cancer detection was similar to that of an experienced radiologist. These findings support the ability of medical AI applications to improve the treatment processes. Tuberculosis detection during chest radiography can be improved using deep convolutional neural networks.[45] Specifically, a model was developed to classify images, which demonstrated the presence/absence of tuberculosis. Hence, the accuracy of the method exceeds 97%, and the analysis of medical data together with experts reduces the error in disease diagnosis. The diagnosis of fibrotic lung disease is based on accurate high-resolution computed tomography.[46] Deep learning applications show accurate results, and thus, disease detection shows human accuracy. The proposed algorithm can aid in optimizing the cost-effective management of clinics or research centers that lack medical personnel and other specialists. The Systolic Blood Pressure Intervention Trial method was developed to test the effectiveness and usability of medical programs for patients with ischemic cardiovascular disease for reducing blood pressure and limit it to recommended values.[47] The combination of the inference and electronic methods shows the effectiveness of blood pressure treatment. Machine learning methods can be used to treat heart failure.[48] The proposed method is based on tensor factorization with the integration of deep phenotypic and trans-omics and accounts for the interactions between patient genetic factors. Winslow et al.[49] applied a statistical learning approach to high-dimensional biomolecular data for heart disease treatment. The study provides evidence of the importance of using multiscale modeling for the connection of organs and provision of anatomical shapes. Han et al.[50] discussed the issue of using AI in orthopedic medicine. The authors claimed three main limitations. First, the use of AI is a time- and finance-consuming process. Second, when AI is applied to big data management, it can lead to spread of confidential medical information. The third problem is that separate AI use in orthopedic surgery is still impossible without human intervention. All of these limitations complicate the AI introduction process. Zhou et al. [51] found and supported numerous studies that machine learning with AI elements can be applied for the prediction and classification of hepatology diseases with large patient datasets. The authors summarized previous studies and concluded that the growth of AI and machine learning applications in hepatology can significantly improve the treatment process. Kochanski

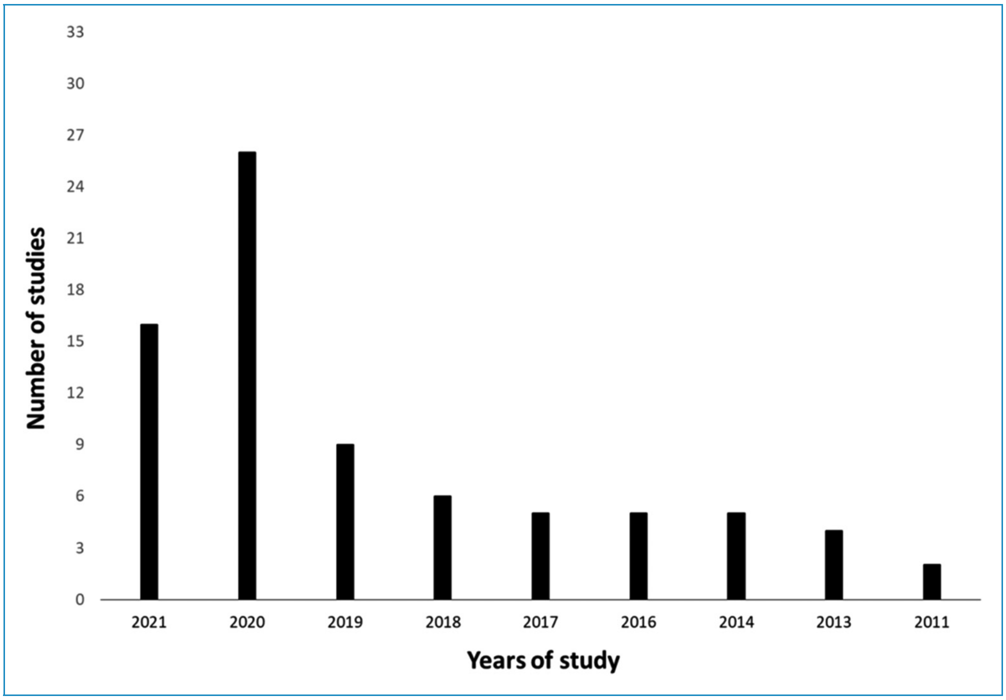

Figure 3. Trend of studies on AI in medical devices and healthcare (January 2011–June 2021).

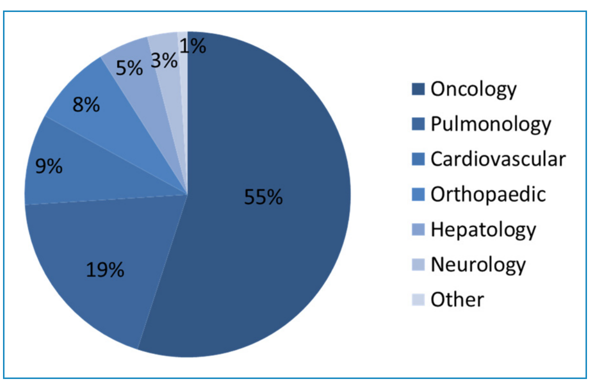

Figure 4. Main areas of AI application in medicine.

et al.[52] applied a deep convolutional neural network and 3D methods to increase the knee treatment efficiency. The developed method can aid in segmenting all knee tissues with a higher accuracy. Musculoskeletal imaging can be more effective for using a deep learning approach. Spann et al.[53] discussed the use of image guidance and robotic systems in spine surgery. The authors described the benefits of using these approaches, such as reducing occupational exposures for medical specialists and patients and supporting the simultaneous introduction of both methods into spine surgery, to improve treatment accuracy. Zhang et al.[54] examined the artificial neural networks application of ANNs for the diagnosis of liver fibrosis using duplex ultrasonography. The authors found that the quantitative diagnosis of liver disease is based on the developed approach with good sensitivity and specificity is effective and can be applied for treatment. Yasaka et al.[55] investigated the possibility of using deep learning techniques in computed tomography to detect liver fibrosis. The developed model with moderate performance demonstrated that deep learning can be applied for the diagnosis of fibrosis in hepatology. Another important and main area of AI application is neurology. Drzezga et al.[56] examined aging-related neurological problems using examples of neurodegenerative Alzheimer's disease. The combined use of positron emission tomography and magnetic resonance imaging is a helpful and promising approach in the field of neurological imaging. Study[57] demonstrated that AI assessment can accurately diagnose dementia in its early stages. AI-based tools based on machine learning methods, such as online assessment tests, allow the application of earlier treatment, prevent diagnostic errors, and reduce the cost of secondary healthcare for neurological diseases. The development of AI-powered neurological issue detection tools has made it easier to treat physical and mental disorders. The application of artificial neural networks for response assessment in neuro-oncology can be introduced to diagnostic processes using magnetic resonance imaging.[58] Furthermore, the authors proposed an effective framework that reflects the replacement of complicated manual disease assessment by automated quantitative magnetic resonance imaging analysis in neuro-oncology.

After reviewing numerous studies, it was found that data collection, analysis, and active treatment are stages of the general treatment process. Clinical imaging collection/

Table 2. Definition of main medical areas for AI application.

Area of Medicine	Definition
Oncology	A branch of medicine that studies cancer tumors from occurrence period, treatment methods, and approaches including ways of prevention.
Pulmonology	A branch of medicine that studies methods of diagnosis and treatment of lungs, bronchi, and trachea diseases.
Cardiovascular	A branch of medicine that studies the methods of diagnosis and treatment of circulatory system diseases including the heart and blood vessels.
Orthopaedics	A branch of medicine that studies the methods of diagnosis and treatment of the skeletal system disease including surgery.
Hepatology	A branch of medicine that studies the methods of diagnosis and treatment of the liver disease (for example, hepatitis, cirrhosis, cancer, immunology problems, and transplantation process).
Neurology	A branch of medicine that studies the methods of diagnosis and treatment of the nervous system disease including problems with the brain and nerves.

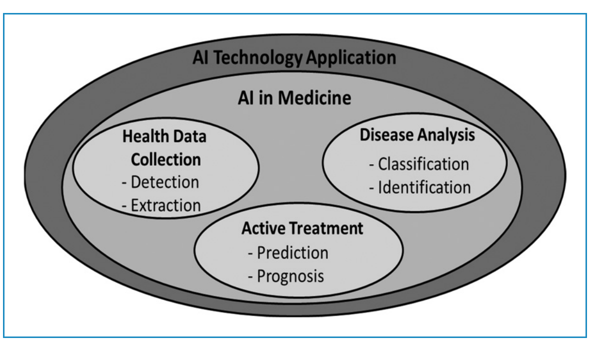

Figure 5. Extracted medical AI application areas by functionality.

processing, machine learning methods, and AI algorithm development for disease and disorder classification (prediction) are involved in each general treatment stage.[59–61]

Overview of artificial intelligence mobile and web apps for medical applications

According to the World Health Organization, eHealth (electronic health) is a special system for increasing cost efficiency and securing information used during the healthcare and treatment processes. The eHealth system can improve the healthcare experience by reducing the distance, time, and effort between treatment participants (users). Each area of eHealth (monitoring, communication, recording, and management) includes different number of users and consequently, different technology nodes. Communication technologies and methods can be improved through eHealth applications in health studies, research, and knowledge delivery. Mobile and Web AI Apps (Apps, AI Apps) are a special issue in medical devices and general medicine with an orientation to usability and user experience. Apps are part of the electronic health (eHealth) system.[62] A summary of previous research results on eHealth system elements is shown in Figure 6.[63–68] Figure 6 contains groups of representative studies of each E-health system – Studies A, B, and C. Examples of representative studies A are Felbaum et al., Higgins et al., Tsapepas et al., Sarkar et al., Liao et al., and van der Meij et al.[64–69]; representative studies B are Warren-Stomberg et al., Liew et al., and Islam et al.[70–72]; representative studies C are Timmers et al., Felbaum et al., Higgins et al., and Tsapepas et al.[63–66]

Figure 6 shows the basic nodes of a general eHealth system, and a review of the literature shows that most of the current references are related to two eHealth nodes of post-treatment management and communication technologies. Moreover, previous studies have shown that the main AI app application areas are surgery, and user-oriented problems are satisfaction and usefulness in post-treatment management and communication technologies.

To support the study summarized in Figure 6, it is necessary to provide a brief overview of previous research. Timmers et al.[63] examined the application of apps for patients after total knee replacement surgery for pain reduction and information perception. It was observed that AI apps for patient self-care can aid in reducing pain and increasing the quality of life and physical functioning. Additionally, the study supports the hypothesis that post-operative care education apps increase satisfaction with information and perceived healthcare. Felbaum et al.[64] introduced app-based instructions for patients after neurosurgery and proved that AI apps are useful in neurosurgical care to improve user experience and satisfaction with medical care. Apps for adjusting the personalized convalescence plan and developing a recovery schedule for each patient after laparoscopic abdominal surgery were tested by van der Meij et al.[69] The authors suggested the use of electronic health interventions in treatment in further studies. Patient-centered mobile applications for monitoring the post-surgery state during the first few weeks, which is critical for patient recovery, have been investigated.[65] Using the smartphone application, doctors were able to monitor patients' states through periodic online surveys. This study illustrated the positive role of an AI app and

Table 3. Literature summarizing main AI medical applications in active treatment process.

Study	AI area	Medical area	Summarized research content
Hosny et al. [40]	Imagine methods	Oncology	Discussion of visualization methods in radiology
Luo et al. [41]	Clinical endoscopy imaging		Development of deep learning method for endoscopy imaging recognition
Abdellatif et al. [42]	Radiology imaging		Convolutional neural networks and variational autoencoder application for imaging
Ardila et al. [43]	Computed tomography		Development of deep learning method for cancer prediction
Li et al. [44]	Ultrasound detection		Development of convolutional neural network model for thyroid cancer detection
Lakhani and Sundaram [45]	Radiology imaging	Pulmonology	Development of deep learning method for tuberculosis detection
Walsh et al. [46]	High-resolution computed tomography		Development of deep learning method for fibrotic lung disease
Johnson et al. [47]	Systolic blood pressure intervention method	Cardiovascular	Intervention method development for reducing blood pressure in ischemic cardiovascular disease
Luo et al. [48]	ML methods		Development of deep learning method based on genetic approach in cardiology
Winslow et al. [49]	ML methods		Development of statistical learning approach for high-dimensional biomolecular data
Han and Tian [50]	General AI introduction	Orthopedics	Limitation of AI application in orthopedic medicine.
Zhou et al. [51]	ML methods and musculoskeletal imaging		Application of deep convolutional neural network and 3D methods to increase knee treatment efficiency
Kochanski et al. [52]	Imaging and robotics systems		Description of AI using benefits for medical specialists and patients in spine surgery
Spann et al. [53]	ML methods	Hepatology	Summarizing of previous studies on effectiveness of machine learning application in hepatology
Zhang et al. [54]	Deep learning methods		Artificial neural network application for diagnostic of liver fibrosis via duplex ultrasonography
Yasaka et al. [55]	Deep learning methods		Deep learning application in computed tomography to detect liver fibrosis.
Drzezga et al. [56]	Positron emission tomography and magnetic resonance imaging	Neurology	Combination introduction of different tomography and imaging methods for neurological treatment.
Hughes [57]	ML methods		Application of AI assessment tool based on ML methods for dementia in early stage treatment.

(continued)

Table 3. Continued.

Study	AI area	Medical area	Summarized research content
Kickingereder et al. [58]	ML methods and magnetic resonance imaging		Application of artificial neural networks for the magnetic resonance imaging in neuro-oncology.
Deyer and Doshi [59]	General AI methods and systems in radiology	All medical areas	Discussion of applied AI systems and approaches in medical radiology and different computer systems
Liew [60]	Deep learning methods and clinical imaging		Discussion of the safe AI application for clinical imaging to improve general radiology practice
Rozynek et al. [61]	General AI methods and systems in diagnostic imaging	General body muscle system	Discussion of AI method application in diagnostic imaging for body muscle system assessment.

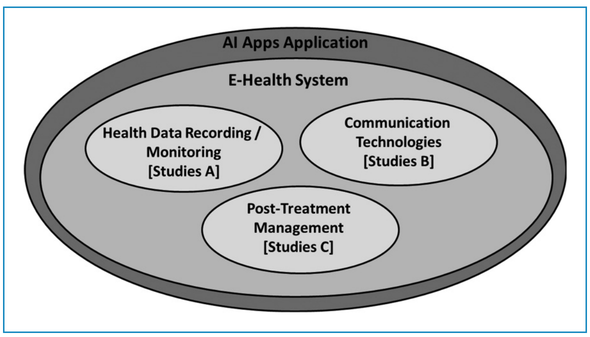

Figure 6. Main extracted elements of an e-health system.

patient satisfaction with the online system. Tsapepas et al.[66] studied apps for patients receiving kidney transplants that aided in understanding the name of medication received after surgery with dose, effects, and interactions with other medicines. Hence, most of the patients correctly answered the control medication survey, and the tested app was helpful in educating users about post-surgery care. The prospect of using apps for home care after medical procedures and surgery was studied by Warren-Stomberg et al.[70] The results suggest that users (patients) have positive attitudes toward the telemedical method with apps that transfer safe health data to the hospital.

Sarkar et al.[67] investigated the usability of mobile health application apps for diabetes, depression, and caregiving to improve and develop further eHealth applications. It was suggested that app developers consider the lack of confidence in technology, frustration with design and navigation, and increase in self-management features. These characteristics are helpful in improving app usability and user satisfaction. Liao et al.[68] studied apps for monitoring the recovery process in the post-discharge period. It was observed that monitoring apps for the post-discharge drainage period can be used with high user satisfaction. Liew et al.[71] observed that the usability of medical apps is an important factor in ensuring the success of health and wellness of users (doctors, patients, and other professionals). Satisfaction with the app is ranked by users as the main usability characteristic that provides the best user experience. However, negative user expectations are linked to charges of apps and advertisements. Moreover, this type of app can aid in improving surgical care in eHealth. Islam et al.[72] investigated eHealth apps among Bangladeshi users and found that the usability of these apps is unsatisfactory and can cause problems for eHealth service consumption.

Based on the studies reviewed in this section, the use of apps facilitates communication between healthcare professionals and patients. However, lack of user satisfaction and app usability can be the main issues in AI apps' perceptions and adoption of new electronic technology. As primary users, patients demonstrate satisfaction and positive attitudes towards online and electronic healthcare applications. Furthermore, it was reported that e-health is gaining popularity, but is still underutilized. Further implementation of new online technologies is required to improve the user experience and patient satisfaction with healthcare services.

Discussion

Artificial intelligence is attracting increasing attention in all fields, including medicine. Although medical AI applications are expanding, there are still limitations and biases.[50,73,74] Summarizing all reviewed research by the treatment process, the main areas of AI engagement include oncology, pulmonology, cardiovascular medicine, orthopedics, hepatology, and neurology. Artificial intelligence can be applied in each step of the treatment, but its main electronic applications are clinical imaging collection/processing, machine learning methods, and AI algorithm development for disease and disorder classification (prediction) [Figure 7[75,76];]. Figure 7 contains groups of representative studies of each AI sub-area – Studies of Machine Learning and Mobile/Web Apps. Examples of representative studies of Machine Learning are Antons and Breidbach[31], Gubbi et al., [32] and Kersting et al.[77]; representative studies of Mobile/Web Apps are Felbaum et al., Higgins et al., and Tsapepas et al.[64–66]

Different machine and deep learning methods, together with neural networks (neural networks), can be grouped into AI analytic machine-learning clusters. AI analytics is described as a cluster of approaches and methods for analyzing big data to reduce the time and effort of researchers and analysts.[78] Most common machine learning methods are logistic regression, support vector machines, decision trees, convolutional neural networks, and naïve Bayes classifiers. Figure 7 shows that the AI approaches of machine and deep learning, neural nets, and various AI apps can be successfully applied to clinical imaging improvement (e.g. ultrasound, MRI, X-ray), detection of the presence/absence of a disease, disease onset prediction, management of treatment process, and medication prescription.

Additionally, it can be observed that AI trends in Figure 7 can be randomly combined, and these combinations can lead to separate important functions during the treatment process.[31–39] Previous studies show AI as an advanced medical technology, which can serve as a treatment process with data collection, data analysis, and monitoring functions to improve the treatment process. It is evident that AI introduction has a large number of barriers and suspicions on the part of users, including the medical staff and patients. Based on this, there is a huge layer of medicine where artificial intelligence is either not used at all or is used minimally. This lack of AI use is felt especially in surgery and direct intervention in the organs, joints, and tissues of patients. Since AI is used in various areas of surgery, including laparoscopy, organ and tissue transplantation, abdominal and neurosurgery, special attention deserves surgery and surgical intervention using AI. Study[79] shows a method to evaluate organs of liver donors in transplantation surgery based on a deep learning approach using image information. The proposed model has accuracy over 90% and helps perform non-invasive organ assessment. An AI model was developed to detect anatomic regions in laparoscopic cholecystectomy with high performance[80] to avoid biliary duct injury. To make AI in medicine more effective, it is necessary to clarify the definition, classification and role of AI-based healthcare methods. Computer vision and imaging are also important and promising AI-based approaches which can be helpful to screen diseases effectively. Decker et al.[81] proposed radiomics as a method for effective lung cancer detection. Authors discuss ability of this method to detect tumors non-invasively. Although this is an emerging field based on AI, it has great potential in diagnosing diseases. Literature review by Gumbs et al.[82] summarized and discussed the computer vision role in autonomous surgery. It was found that digitized visual information is the living application of computer vision in surgery, but further development of medical imaging will be helpful to improve treatment efficiency and decrease invasive interventions. The article also shows that further development in this direction will lead to an increase in autonomous actions in treatment. However, for significant improvement in this area, it is necessary that surgeons recognize the importance and possibilities of AI and improve their skills in communicating with such technologies. The previous study[83] provides an introduction to the concept of artificial intelligence surgery and demonstrates that AI in surgery should also include robotization, and not just machine/deep learning and computer vision. Authors believe that robotic surgery will provide a base for autonomous actions during intervention that will improve surgery results, connection between doctor and patients in pre-operative, intra-operative, and post-operative treatment stages. This medical issue is connected with a research question about autonomy in surgery. Gumbs et al.[84] discussed the issue of distrust and wariness associated with the use of AI-based devices in surgery. This study distinguishes six levels of autonomy, ranging from the level "0" without the use of AI to the level "5" of full autonomous surgery; and separates a few AI types of machine learning, deep learning, and computer vision. A clearer understanding of AI levels and types is necessary for surgeons to do their job more efficiently and safely for patients. The positive result of AI application corresponds to an increase in productivity, accuracy (efficiency) of diagnostics and treatment, reduction in treatment time and costs, and improvement in post-treatment care.[57,85,86]

In the field of medical imaging (including data collection tasks for future treatment), the use of AI technologies can improve the accuracy of the recognition of foci of disease and neoplasms, which is comparable to the work of a medical expert.[41] Conversely, the best results are obtained when the AI and healthcare professional's assessment work together.[45] Furthermore, machine learning, deep

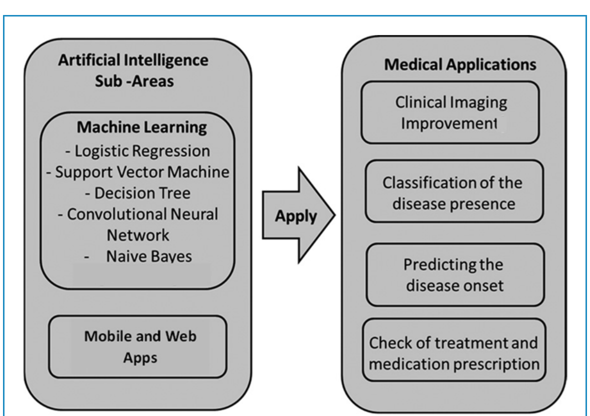

Figure 7. AI electronic trends in medicine.

learning, and algorithms developed on this can aid in increasing the efficiency of predicting the occurrence of a disease, classifying an existing disease, and checking the prescribed treatment method and medications (including dosage).[77,33] It is also easier to manage big health data when there is an AI algorithm for collecting, evaluating, and analyzing data.

Another problem associated with the introduction of AI medical technologies and healthcare data management is the method of medical AI verification, as well as AI-based research replication. Previous studies[87–90] show that the main problems are the lack of standards and regulation in the collection and processing of medical data; the secrecy of AI algorithms due to which the multi-level data analysis processes are not obvious to users and it is difficult to understand how artificial intelligence mathematically processes the data and analysis. For the same reason, replication of AI studies is difficult. Replication of studies is important especially in medicine to prove the results obtained. This process also requires a large data set, which is also a problem in medicine, since the use of patient data must have increased security and integrity. Basically, these data cannot be disclosed due to the need for patient privacy. Based on this, a previous study[88] proposes a validation model for AI in precision medicine using the example of oncology treatment. The proposed algorithm contains the following steps: determining the application of AI and the target medical group; the AI technology analysis period and data set used; ensuring the security of the data used; AI evaluation criteria and metrics; ensuring the transparency of the AI functioning. The secrecy of AI approaches has been discussed by Petch, Di, and Nelson.[90] This study shows that due to a lack of understanding of deep and multi-level processes, medical professionals still have mistrust in healthcare AI since this is connected with the life and health of people. Authors studied techniques of explainable machine learning and discussed importance of AI transparency for medical purposes as well as some limitations of existing AI methods. Since the security of medical data is a necessity, a solution to this problem was proposed by Almalawi et al.[87] The authors proposed an algorithm for encrypting private data. This method is based on the approach and encrypts patient data before it enters the cloud, generating secure keys. The proposed method is cost-effective as it minimizes the time spent on encryption and access to data, increasing confidentiality. Pandey et al.[89] proposed a systematic literature review on the medical data integrity issue. The authors presented the main data integrity problems, methods and techniques in the field of medical data security, as well as the challenges and future in this area. One of the main and promising data integrity techniques has been identified as blockchain. Based on previous research and considering the importance of research on AI safety and validation, the proposed results can help in understanding which deep learning and machine learning methods can improve the patient data processing and how best to use them.

Although the use of artificial intelligence facilitates and improves the process of providing medical services, there are a number of problems and barriers to the widespread adoption of AI. One limitation is the high cost of the devices with AI elements.[50] This corresponds to the paradox that occurs very often the use of these technologies should reduce the cost of treatment. However, artificial technologies are quite expensive. Second, there is still a lack of user trust in AI.[22] This is due to the fact that information processing in AI devices is hidden from the doctor and patient, and there is also a paucity of long-term research plans for the development and improvement of AI technologies.[50] The combination of these factors leads to suspicion and lack of trust in artificial intelligence. The ethical aspect of the use of artificial intelligence is also a challenge to the expansion of clinical AI.[50,91–94] This involves two aspects: work with big medical data and introduction of AI into controversial medical areas, for example, related to the study of genes and their modifications. To address this problem, it is necessary to develop a clear set of legislative regulations for genetic engineering as well as improve the reliability of AI software to avoid the leakage of patient personal data. Another limitation is related to the ease of use of AI equipment or devices by doctors (especially in high-precision surgical areas) as well as the responsibility for medical errors during or after AI use. The solution to these problems is also associated with the legislative consolidation of responsibility for clinical errors in relation to doctors, AI developers, or AI providers (identification of responsible AI agents). Additionally, developers should provide a user-centric AI interface and system to reduce usage time, complexity of use, and physician fatigue, and improve the interpretability of the obtained AI results.[22]

Based on previous studies[67,68] user experience and usability are discussed in the fields of medicine and medical AI[95,96] related to the aforementioned barriers. Cutillo et al.[95] summarized and proposed a few usability characteristics, which are especially important in medical AI, including error prevention via system feedback, medical AI intervention should be clearly understood in terms of comparison with the usual medical care process, and a connection system between medical users, disciplines, and sectors should be established to provide the most useful treatment system. The proposed approach is consistent with the findings of Bitkina, Kim, and Park.[96] In this study, the authors explained the usability concept of medical device assessment based on the following principles. First, usability can be evaluated as a subset of the medical user experience. Second, medical devices and consumer goods must be evaluated using different criteria. Third, the medical usability evaluation approach is dependent on the type of product in the expert and medical systems. Summarizing the aforementioned studies, it should be noted that the use of medical devices and systems, including artificial intelligence, is a separate concept, and the approach to assessing medical user experience should differ from that of other services and products.

Despite the presence of all the barriers and problems in the clinical use of artificial intelligence, this area is promising for improving the diagnosis of diseases, treatment process, and post-treatment care.[97–100] Developers should pay particular attention to expanding the scope of AI in medicine such as surgery.

Limitations of study

Despite the results and findings obtained, the presented article has a number of limitations. Firstly, the concept of artificial intelligence is rather vague even with an encyclopedic definition. Accordingly, when reviewing the existing literature, it must be understood that each author has his own final understanding of this field. Based on this, the review includes previous AI research, but adjusted for the individual perceptions of the authors and this cannot be unified at the current moment. Secondly, a literature review, even in the presence of a specific methodology, always has an omission of literature sources, since they are updated every day and it is impossible to fully follow this. Third, despite the abundance of literature in the area under discussion, the number of published studies in the presented topic is still not enough and the selection of resources requires increased the attention and time.

Conclusion

This article provides an overview of the current state of artificial intelligence in the field of medical technologies. Over 100 published and gray literature sources were reviewed and evaluated, and major trends in medical AI were identified. Statistical analysis of previous literature shows that the leaders in medical AI research are the USA, Canada, UK, and China. Furthermore, the number of published AI studies started rapidly increasing from 2005 to 2006.

The main branches of medicine that use AI are oncology, pulmonology, cardiovascular medicine, orthopedics, hepatology, and neurology. The main applications of AI in medical devices can be classified into three major groups: collection of medical data, medical data analysis, and active treatment processes. Special attention to the use of AI is focused on clinical imaging, data exchange, big data processing, and machine-learning algorithm development to predict and classify diseases.

Problems and challenges in AI use include the high cost of devices with AI elements, lack of user trust in AI, long-term research plans for AI development, ethical issues of AI use, ease of use of AI equipment or devices by doctors, and responsibility for medical errors due to AI use. The solutions to these problems are associated with the legislative consolidation of principles for the development and use of AI in medicine as well as the creation of AI products with user-centered design and clear future development plans. Despite all the difficulties of AI use, previous research has shown that this is the most promising area in the medical sector.

In the present study, we identified the main areas of application of artificial intelligence in medical technologies, the problems associated with its implementation, and potential ways to accelerate and expand the use of clinical AI. This study can contribute in the various fields of medicine, AI, user experience, and human factors. Based on the extracted findings, AI application in the medical and healthcare area can be improved by understanding the technical, partially legal, and ethical issues in the collaboration between medical professionals and AI technologies. Based on the extracted AI application focus, it can be expanded through accounting for less involved medical areas to increase healthcare service quality. User experience can be improved from both sides of healthcare professionals and patients. Doctors and other professionals in future can have benefits of an increase in the understanding of the functioning of new devices and a subsequent increase in the speed of medical care and the accuracy of treatment, as well as a decrease in workload. In turn, patients can experience immediate improvements in the health care and quality of life. The field of human factors can also be further developed by improving the principles of functioning and using AI not only for medical purposes, but also to alleviate the physical, emotional, and workload in various areas, such as those associated with physical or other monotonous work. Moreover, the improvement of the ethical and legal conditions for the use of AI will help expand its implementation in society with an understanding of the potential risks. The findings will be useful for healthcare professionals, AI engineers, AI developers, AI providers, and medical and AI researchers to improve the circulation and use of medical AI at all stages of its lifecycle.

Contributorship: OB wrote the first draft of the manuscript. JP and HK reviewed and edited the manuscript and approved the final version of the manuscript.

Declaration of conflicting interests: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical approval: Not applicable; no human subjects involvement.

Funding: The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. NRF-2021R1A2C4002641 and NRF-2022R1I1A1A01073303).

Guarantor: JP

ORCID iDs: Jaehyun Park https://orcid.org/0000-0002-5264-6941
Hyun K. Kim https://orcid.org/0000-0002-5192-9405

Research ethics and patient consent: Not applicable because this article does not contain any studies with human or animal subjects. Informed consent for patients was not required for this study was done based on a literature review.

References

1. APACMed website, https://apacmed.org (2023, accessed 30 May 2023)
2. Segato A, Marzullo A, Calimeri F, et al. Artificial intelligence for brain diseases: a systematic review. *APL Bioeng* 2020; 4: 041503.
3. Malik PA, Pathania M and Kumar Rathaur VK. Overview of artificial intelligence in medicine. *J Family Med Prim Care* 2019; 8: 2328–2331.
4. Pashkov VM, Harkusha AO and Harkusha YO. Artificial intelligence in medical practice: regulative issues and perspectives. *Wiad Lek* 2020; 73: 2722–2727.
5. Lv J, Deng S and Zhang L. A review of artificial intelligence applications for antimicrobial resistance. *Biosaf Health* 2021; 3: 22–31.
6. Loh E. Medicine and the rise of the robots: a qualitative review of recent advances of artificial intelligence in health. *BMJ Lead* 2018; 2: 59–63.
7. Makaremi M, Lacaule C and Mohammad-Djafari A. Deep learning and artificial intelligence for the determination of the cervical vertebra maturation degree from lateral radiography. *Entropy* 2019; 21: 1222.
8. Kaul V, Enslin S and Gross S. History of artificial intelligence in medicine. *Gastrointest Endosc* 2020; 92: 807–812.
9. Ploug T and Holm S. The right to refuse diagnostics and treatment planning by artificial intelligence. *Med Health Care Philos* 2020; 23: 107–114.
10. Panch T, Szolovits P and Atun R. Artificial intelligence, machine learning and health systems. *J Glob Health* 2018; 8: PMC6199467.
11. Haenlein M and Kaplan A. A brief history of artificial intelligence: on the past, present, and future of artificial intelligence. *Calif Manage Rev* 2019; 61: 5–14.
12. Howard J. Artificial intelligence: implications for the future of work. *Am J Ind Med* 2019; 62: 917–926.
13. Letzen B, Wang CJ and Chapiro J. The role of artificial intelligence in interventional oncology: a primer. *J Vasc Interv Radiol* 2019; 30: 38–41.e1.
14. Alexander G and Staggers N. A systematic review on the designs of clinical technology: findings and recommendations for future research. *ANS Adv Nurs Sci* 2009; 32: 252–279.
15. Matias I, Garcia N, Pirbhulal S, et al. Prediction of atrial fibrillation using artificial intelligence on electrocardiograms: a systematic review. *Comput Sci Rev* 2021; 39: 100334.
16. Rong G, Mendez A, Assi EB, et al. Artificial intelligence in healthcare: review and prediction case studies. *Engineering* 2020; 6: 291–301.
17. Davenport T and Kalakota R. The potential for artificial intelligence in healthcare. *Future Healthc J* 2019; 6: 94–98.
18. Choudhury A. A framework for safeguarding artificial intelligence systems within healthcare. *Br J Health Care Manag* 2019; 25: 1–6.
19. Alsuliman T, Humaidan D and Sliman L. Machine learning and artificial intelligence in the service of medicine: necessity or potentiality? *Curr Res Transl Med* 2020; 68: 245–251.
20. LaRosa E and Danks D. Impacts on trust of healthcare AI. In: AIES '18: Proceedings of the 2018 AAAI/ACM Conference on AI, Ethics, and Society, New Orleans, LA, USA, 2018, pp.210–215.
21. Asan O, Bayrak AE and Choudhury A. Artificial intelligence and human trust in healthcare: focus on clinicians. *J Med Internet Res* 2020; 22: e15154.
22. Donovan F. TechTarget site, https://hitinfrastructure.com/news/fear-of-artificial-intelligence-in-healthcare-can-delay-benefits. (2018, accessed 27 September 2022).
23. Shinners L, Aggar C, Grace S, et al. Exploring healthcare professionals' perceptions of artificial intelligence: validating a questionnaire using the e-Delphi method. *Digit Health* 2021; 7: 20552076211003433.
24. Hengstler M, Enkel E and Duelli S. Applied artificial intelligence and trust—the case of autonomous vehicles and medical assistance devices. *Technol Forecast Soc Change* 2016; 105: 105–120.
25. Gille F, Jobin A and Ienca M. What we talk about when we talk about trust: theory of trust for AI in healthcare. *Intell Based Med* 2020; 1–2: 100001.
26. Hervieux S and Wheatley A. Perceptions of artificial intelligence: a survey of academic librarians in Canada and the United States. *J Acad Librariansh* 2021; 47: 102270.
27. PRISMA guidelines site, http://prisma-statement.org (accessed 30 May 2023)
28. AHMD The American Heritage Medical Dictionary) by Editors of the American Heritage Dctionary, 2007.
29. OMV Site "Medicinenet", www.medicinenet.com (accessed 27 September 2022).
30. MWV Site, https://www.merriam-webster.com/ (accessed 27 September 2022).
31. Antons D and Breidbach CF. Big data, big insights? Advancing service innovation and design with machine learning. *J Serv Res* 2018; 21: 17–39.
32. Gubbi S, Hamet P, Tremblay J, et al. Artificial Intelligence and Machine Learning in endocrinology and metabolism: the dawn of a new era. *Front Endocrinol* 2019; 10: 185.
33. Miotto R, Wang F, Wang S, et al. Deep learning for healthcare: review, opportunities and challenges. *Brief Bioinform* 2018; 19: 1236–1246.
34. Elbadawi M, McCoubrey L, Gavins F, et al. Harnessing artificial intelligence for the next generation of 3D printed medicines. *Adv Drug Deliv Rev 2021*; 175: 113805.

35. Neill DB. Using artificial intelligence to improve hospital inpatient care. *IEEE Intell Syst* 2013; 28: 92–95.
36. Shahid N, Rappon T and Berta W. Applications of artificial neural networks in health care organizational decision-making: a scoping review. *PLoS ONE* 2019; 14: e0212356.
37. Diprose W and Buist N. Artificial intelligence in medicine: humans need not apply? *N Z Med J* 2016; 129: 73–76.
38. Patel VL, Shortliffe EH, Stefanelli M, et al. The coming of age of artificial intelligence in medicine. *Artif Intell Med* 2009; 46: 5–17.
39. Kulkarni S. Artificial intelligence in medicine: where are we now? *Acad Radiol* 2020; 27: 62–70.
40. Hosny A, Parmar C, Quackenbush J, et al. Artificial intelligence in radiology. *Nat Rev Cancer* 2018; 18: 500–510.
41. Luo H, Xu G, Li C, et al. Real-time artificial intelligence for detection of upper gastrointestinal cancer by endoscopy: a multicentre, case-control, diagnostic study. *Lancet Oncol* 2019; 20: 1645–1654.
42. Abdellatif AA, Mohamed A, Chiasserini CF, et al. Edge computing for smart health: context-aware approaches, opportunities, and challenges. *IEEE Netw* 2019; 33: 196–203.
43. Ardila D, Kiraly AP, Bharadwaj S, et al. End-to-end lung cancer screening with three-dimensional deep learning on low-dose chest computed tomography. *Nat Med* 2019; 25: 954–961.
44. Li X, Zhang S, Zhang Q, et al. Diagnosis of thyroid cancer using deep convolutional neural network models applied to sonographic images: a retrospective, multicohort, diagnostic study. *Lancet Oncol* 2019; 20: 193–201.
45. Lakhani P and Sundaram B. Deep learning at chest radiography: automated classification of pulmonary tuberculosis by using convolutional neural networks. *Radiology* 2017; 284. doi:10.1148/radiol.2017162326
46. Walsh SLF, Calandriello L, Silva M, et al. Deep learning for classifying fibrotic lung disease on high-resolution computed tomography: a case-cohort study. *Lancet Respir Med* 2018; 6: 837–845.
47. Johnson KW, Glicksberg BS, Hodos RA, et al. Causal inference on electronic health records to assess blood pressure treatment targets: an application of the parametric g formula. *Biocomputing* 2018; 23: 180–191.
48. Luo Y, Ahmad FS and Shah SJ. Tensor factorization for precision medicine in heart failure with preserved ejection fraction. *J of Cardiovasc Trans Res* 2017; 10: 305–312.
49. Winslow RL, Trayanova N, Geman D, et al. Computational medicine: translating models to clinical care. *Sci Transl Med* 2012; 4: 158rv11.
50. Han XG and Tian W. Artificial intelligence in orthopedic surgery: current state and future perspective. *Chin Med J* 2019; 132: 2521–2523.
51. Zhou Z, Zhao G, Kijowski R, et al. Deep convolutional neural network for segmentation of knee joint anatomy. *Magn Reson Med* 2018; 80: 2759–2770.
52. Kochanski RB, Lombardi JM, Laratta JL, et al. Image-guided navigation and robotics in spine surgery. *Neurosurgery* 2019; 84: 1179–1189.
53. Spann A, Yasodhara A, Kang J, et al. Applying machine learning in liver disease and transplantation: a comprehensive review. *Hepatology* 2020; 71: 1093–1105.
54. Zhang L, Li QY, Duan YY, et al. Artificial neural network aided non-invasive grading evaluation of hepatic fibrosis by duplex ultrasonography. *BMC Med Inform Decis Mak* 2012; 12: 55.
55. Yasaka K, Akai H, Kunimatsu A, et al. Deep learning for staging liver fibrosis on CT: a pilot study. *Eur Radiol* 2018; 28: 4578–4585.
56. Drzezga A, Barthel H, Minoshima S, et al. Potential clinical applications of PET/MR imaging in neurodegenerative diseases. *J Nucl Med* 2014; 55: 47S–55S.
57. Hughes O. Using AI assessment to tackle dementia in ultra-early stages, https://www.digitalhealth.net/2019/09/using-ai-assessment-tackle-dementia-ultra-early-stages/ (2019, accessed 27 September 2022).
58. Kickingereder P, Isensee F, Tursunova I, et al. Automated quantitative tumour response assessment of MRI in neuro-oncology with artificial neural networks: a multicentre, retrospective study. *Lancet Oncol* 2019; 20: 728–740.
59. Deyer T and Doshi A. Application of artificial intelligence to radiology. *Ann Transl Med* 2019; 7: 230.
60. Liew C. The future of radiology augmented with Artificial Intelligence: a strategy for success. *Eur J Radiol* 2018; 102: 152–156.
61. Rozynek M, Kucybała I, Urbanik A, et al. The use of artificial intelligence in the imaging of sarcopenia: a narrative review of current status and perspectives. *Nutrition* 2021: 111227. doi:10.1016/j.nut.2021.111227
62. Orlovsky C. 7 Top patient apps in eHealth, https://www.americanmobile.com/nursezone/nursing-news/7-top-patient-apps-in-ehealth/. (accessed 27 September 2022).
63. Timmers T, Janssen L, van der Weegen W, et al. The effect of an app for day-to-day postoperative care education on patients with total knee replacement: randomized controlled trial. *JMIR Mhealth Uhealth* 2019; 7: e15323.
64. Felbaum DR, Stewart JJ, Anaizi AN, et al. Implementation and evaluation of a smartphone application for the perioperative care of neurosurgery patients at an academic medical center: implications for patient satisfaction, surgery cancelations, and readmissions. *Oper Neurosurg* 2018; 14: 303–331.
65. Higgins J, Semple J, Murnaghan L, et al. Mobile web-based follow-up for postoperative ACL reconstruction: a single-center experience. *Orthop J Sports Med* 2017; 5: 2325967117745278.
66. Tsapepas DS, Salerno D, Jandovitz N, et al. Using technology to enhance medication regimen education after solid organ transplantation. *Am J Health Syst Pharm* 2018; 75(23): 1930–1937.
67. Sarkar U, Gourley GI, Lyles CR, et al. Usability of commercially available mobile applications for diverse patients. *J Gen Intern Med* 2016; 31: 1417–1426.
68. Liao C, Wu Y, Cheng C, et al. An image-based mobile health app for postdrainage monitoring: usability study. *J Med Internet Res* 2020; 22: e17686.
69. van der Meij E, Huirne JA, Ten Cate AD, et al. A perioperative eHealth program to enhance postoperative recovery after abdominal surgery: process evaluation of a randomized controlled trial. *J Med Internet Res* 2018; 20: e1.
70. Warren-Stomberg M, Jacobsson J, Brattwall M, et al. At-home monitoring after surgery/anaesthesia - a challenge. *J Eval Clin Pract* 2016; 22: 882–886.

71. Liew MS, Zhang J, See J, et al. Usability challenges for health and wellness mobile apps: mixed-methods study among mHealth experts and consumers. *JMIR Mhealth Uhealth* 2019; 7: e12160.
72. Islam MN, Karim MM, Inan TT, et al. Investigating usability of mobile health applications in Bangladesh. *BMC Med Inform Decis Mak* 2020; 20: 19.
73. Sutton RA and Sharma P. Overcoming barriers to implementation of artificial intelligence in gastroenterology. *Best Pract Res Clin Gastroenterol* 2021; 52–53: 101732.
74. Krawczuk J and Łukaszuk T. The feature selection bias problem in relation to high-dimensional gene data. *Artif Intell Med* 2016; 66: 63–71.
75. Jabr YA and Sandhu J. Limitations of health technology implementation: a commentary on "artificial intelligence, regenerative surgery, robotics? What is realistic for the future of surgery?". *Ann Med Surg (Lond)* 2020; 60: 702–703.
76. Sloane EB and Silva RJ. Chapter 83 - Artificial intelligence in medical devices and clinical decision support systems. *Clinical Engineering Handbook (Second Edition)* 2020: 556–568.
77. Kersting K. Machine Learning and Artificial Intelligence: two fellow travelers on the quest for intelligent behavior in machines. *Front Big Data* 2018; 1: 6.
78. Anodot site, https://www.anodot.com/learning-center/ai-analytics/ (accessed 27 September 2022).
79. Ugail H, Abubakar A, Elmahmudi A, et al. The use of pre-trained deep learning models for the photographic assessment of donor livers for transplantation. *Artif Intell Med* 2022; 2: 101–119.
80. Liu R, An J, Wang Z, et al. Artificial intelligence in laparoscopic cholecystectomy: does computer vision outperform human vision? *Artif Intell Med* 2022; 2: 80–92.
81. Decker JM, Sesti J, Turner AL, et al. The cassandra paradox: looking into the crystal ball of radiomics in thoracic surgery. *Artif Intell Med* 2022; 2: 57–63.
82. Gumbs AA, Grasso V, Bourdel N, et al. The advances in computer vision that are enabling more autonomous actions in surgery: a systematic review of the literature. *Sensors* 2022; 22: 4918.
83. Gumbs AA, Perretta S, d'Allemagne B, et al. What is artificial intelligence surgery? *Artif Intell Med* 2021; 1: 1–10.
84. Gumbs AA, Alexander F, Karcz K, et al. White paper: definitions of artificial intelligence and autonomous actions in clinical surgery. *Artif Intell Med*. 2022; 2: 93–100.
85. Buch VH, Ahmed I and Maruthappu M. Artificial intelligence in medicine: current trends and future possibilities. *Br J Gen Pract* 2018; 68: 143–144.
86. Tang KJW, Ang CKE, Constantinides T, et al. Artificial intelligence and machine learning in emergency medicine. *Biocybern Biomed Eng* 2021; 41: 156–172.
87. Almalawi A, Khan AI, Alsolami F, et al. Managing security of healthcare data for a modern healthcare system. *Sensors* 2023; 23: 3612.
88. Tsopra R, Fernandez X, Luchinat C, et al. A framework for validating AI in precision medicine: considerations from the European ITFoC consortium. *BMC Med Inform Decis Mak* 2021; 21: 274.
89. Pandey AK, Khan AI, Abushark YB, et al. Key issues in healthcare data integrity: analysis and recommendations. *IEEE Access* 2020; 8: 40612–40628.
90. Petch J, Di S and Nelson W. Opening the black box: the promise and limitations of explainable machine learning in cardiology. *Can J Cardiol* 2022; 38: 204–213.
91. Keskinbora KH. Medical ethics considerations on artificial intelligence. *J Clin Neurosci* 2019; 64: 277–282.
92. Morley J, Machado CCV, Burr C, et al. The ethics of AI in health care: a mapping review. *Soc Sci Med* 2020; 260: 13172.
93. Currie G and Hawk KE. Ethical and legal challenges of artificial intelligence in nuclear medicine. *Semin Nucl Med* 2021; 51: 120–125.
94. Anom BY. Ethics of big data and artificial intelligence in medicine. *Ethics Med Public Health* 2020; 15: 100568.
95. Cutillo CM, Sharma KR, Foschini L, et al. Machine intelligence in healthcare-perspectives on trustworthiness, explainability, usability, and transparency. *NPJ Digit Med* 2020; 3: 47.
96. Bitkina OV, Kim HK and Park J. Usability and user experience of medical devices: an overview of the current state, analysis methodologies, and future challenges. *Int J Ind Ergon* 2020; 76: 102932.
97. Kapoor R, Walters SP and Al-Aswad LA. The current state of artificial intelligence in ophthalmology. *Surv Ophthalmol* 2019; 64: 233–240.
98. Beckers R, Kwade Z and Zanca F. The EU medical device regulation: implications for artificial intelligence-based medical device software in medical physics. *Phys Med* 2021; 83: 1–8.
99. Greco L, Percannella G, Ritrovato P, et al. Trends in IoT based solutions for health care: moving AI to the edge. *Pattern Recognit Lett* 2020; 135: 346–353.
100. Becker A. Artificial intelligence in medicine: what is it doing for us today? *Health Policy Technol* 2019; 8: 198–205.