

Review Article
Medical Informatics



Artificial Intelligence in Health Care: Current Applications and Issues

Chan-Woo Park ,^{1*} Sung Wook Seo ,^{1*} Noeul Kang ,² BeomSeok Ko ,³
Byung Wook Choi ,⁴ Chang Min Park ,⁵ Dong Kyung Chang ,⁶ Hwioung Kim ,⁴
Hyunchul Kim ,⁷ Hyunna Lee ,⁸ Jinhee Jang ,⁹ Jong Chul Ye ,¹⁰
Jong Hong Jeon ,¹¹ Joon Beom Seo ,¹² Kwang Joon Kim ,¹³ Kyu-Hwan Jung ,¹⁴
Namkug Kim ,¹⁵ Seungwook Paek ,¹⁶ Soo-Yong Shin ,¹⁷ Soyoung Yoo ,⁸
Yoon Sup Choi ,¹⁸ Youngjun Kim ,¹⁹ and Hyung-Jin Yoon ²⁰

OPEN ACCESS

Received: Jun 26, 2020
Accepted: Sep 23, 2020

Address for Correspondence:

Hyung-Jin Yoon, MD

Department of Biomedical Engineering, Seoul National University College of Medicine, 103 Daehak-ro, Jongno-gu, Seoul 03080, Korea.
E-mail: hjoyoon@snu.ac.kr

*Chan-Woo Park and Sung Wook Seo contributed equally to this work.

© 2020 The Korean Academy of Medical Sciences.

This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<https://creativecommons.org/licenses/by-nc/4.0/>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

ORCID iDs

Chan-Woo Park
<https://orcid.org/0000-0002-4332-5863>
Sung Wook Seo
<https://orcid.org/0000-0001-9048-0367>
Noeul Kang
<https://orcid.org/0000-0003-0925-3891>
BeomSeok Ko
<https://orcid.org/0000-0001-7831-7874>
Byung Wook Choi
<https://orcid.org/0000-0002-8873-5444>
Chang Min Park
<https://orcid.org/0000-0003-1884-3738>
Dong Kyung Chang
<https://orcid.org/0000-0001-8925-4629>
Hwioung Kim
<https://orcid.org/0000-0001-7778-8973>

¹Department of Orthopedic Surgery, Samsung Medical Center, School of Medicine, Sungkyunkwan University, Seoul, Korea

²Division of Pulmonary and Critical Care Medicine, Department of Medicine, Samsung Medical Center, School of Medicine, Sungkyunkwan University, Seoul, Korea

³Department of Surgery, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Korea

⁴Department of Radiology, Severance Hospital, Yonsei University College of Medicine, Seoul, Korea

⁵Department of Radiology, Seoul National University College of Medicine, Seoul, Korea

⁶Division of Gastroenterology, Department of Medicine, Samsung Medical Center, School of Medicine, Sungkyunkwan University, Seoul, Korea

⁷Department of R&D Planning, Korea Health Industry Development Institute (KHIDI), Cheongju, Korea

⁸Health Innovation Big Data Center, Asan Institute for Life Science, Asan Medical Center, Seoul, Korea

⁹Department of Radiology, Seoul St. Mary's Hospital, College of Medicine, The Catholic University of Korea, Seoul, Korea

¹⁰Department of Bio and Brain Engineering, Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Korea

¹¹Protocol Engineering Center, Electronics and Telecommunications Research Institute (ETRI), Daejeon, Korea

¹²Department of Radiology, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Korea

¹³Division of Geriatrics, Department of Internal Medicine, Severance Hospital, Yonsei University College of Medicine, Seoul, Korea

¹⁴VUNO Inc., Seoul, Korea

¹⁵Department of Convergence Medicine, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Korea

¹⁶Lunit Inc., Seoul, Korea

¹⁷Big Data Research Center, Samsung Medical Center, School of Medicine, Sungkyunkwan University, Seoul, Korea

¹⁸Digital Healthcare Partners, Seoul, Korea

¹⁹Center for Bionics, Korea Institute of Science and Technology (KIST), Seoul, Korea

²⁰Department of Biomedical Engineering, Seoul National University College of Medicine, Seoul, Korea

ABSTRACT

In recent years, artificial intelligence (AI) technologies have greatly advanced and become a reality in many areas of our daily lives. In the health care field, numerous efforts are being made to implement the AI technology for practical medical treatments. With the rapid developments in machine learning algorithms and improvements in hardware performances, the AI technology is expected to play an important role in effectively analyzing and utilizing extensive amounts of health and medical data. However, the AI technology has various unique characteristics that are different from the existing health care technologies. Subsequently, there are a number of areas that need to be supplemented within the current health care system for the AI to be utilized more effectively and frequently in health care. In addition, the number of medical practitioners and public that accept AI in the health care is still low; moreover, there are various concerns regarding the safety and reliability of AI technology

Hyunchul Kim 
<https://orcid.org/0000-0003-0468-7965>
 Hyunna Lee 
<https://orcid.org/0000-0003-1669-3086>
 Jinhee Jang 
<https://orcid.org/0000-0002-3386-1208>
 Jong Chul Ye 
<https://orcid.org/0000-0001-9763-9609>
 Jong Hong Jeon 
<https://orcid.org/0000-0002-6479-2604>
 Joon Beom Seo 
<https://orcid.org/0000-0003-0271-7884>
 Kwang Joon Kim 
<https://orcid.org/0000-0002-5554-8255>
 Kyu-Hwan Jung 
<https://orcid.org/0000-0002-6626-6800>
 Namkug Kim 
<https://orcid.org/0000-0002-3438-2217>
 Seungwook Paek 
<https://orcid.org/0000-0002-2083-8236>
 Soo-Yong Shin 
<https://orcid.org/0000-0002-2410-6120>
 Soyoung Yoo 
<https://orcid.org/0000-0002-2953-508X>
 Yoon Sup Choi 
<https://orcid.org/0000-0002-5207-8198>
 Youngjun Kim 
<https://orcid.org/0000-0002-7832-3200>
 Hyung-Jin Yoon 
<https://orcid.org/0000-0003-4432-4894>

Disclosure

The authors have no potential conflicts of interest to disclose.

Author Contributions

Conceptualization: Yoon HJ, Seo JB. Writing - original draft: Park CW, Seo SW, Kang N. Writing - review & editing: Ko BS, Choi BW, Park CM, Chang DK, Kim H, Kim H, Lee H, Jang J, Ye JC, Jeon JH, Seo JB, Kim KJ, Jung KH, Kim N, Paek S, Shin SY, Yoo S, Choi YS, Kim Y, Yoon HJ.

implementations. Therefore, this paper aims to introduce the current research and application status of AI technology in health care and discuss the issues that need to be resolved.

Keywords: Artificial Intelligence; Machine Learning; Health Care; Application; Issue

INTRODUCTION

Continuous developments in artificial intelligence (AI) technologies are expected to bring innovations to the future of health care. Machine learning, a subfield of AI, is the study of computer algorithm that is automatically improved through experience by applying mathematical approaches.¹ Deep learning, a subset of machine learning, refers to an algorithm that learns by processing input data through artificial neural networks that mimic neurons in the biologic brain.² The explosive growth of digital data, expansion of computing power fueled by innovation in hardware technologies, such as graphics processing unit, and rapid developments in machine learning algorithms, popularly implemented using deep learning, are all leaving a significant mark in the health care field. Accordingly, numerous medical journals have already published vast number of studies analyzing massive amounts of health data by using machine learning technology to diagnose and treat patients.^{3,4} Further, various studies have shown that applying AI in health care gives better results compared with the existing technologies. Some of these studies include analyzing medical images with AI technology to discriminate images and use them for treatments; predicting the course of a disease through various medical and health care data; developing medical devices that can support decision-making during treatments or for diagnosis; and encrypting medical data.⁵⁻¹¹

Further, various attempts have been made to develop and commercialize AI-based medical devices. In addition to the top medical device manufacturers, such as General Electric, Siemens, and Phillips, leading global information technology (IT) companies, such as Samsung, Google, Apple Microsoft, and Amazon, and numerous competitive startups have demonstrated significant research achievements in the use of AI in health care. Based on these research achievements, the companies are working to establish business achievements as well. Additionally, these efforts made by the industry and medical field are contributing to the successful approval of AI-based medical devices by regulatory agencies. In the U.S., the Food and Drug Administration (FDA) approved the use of AI-based medical devices for the first time in 2017, and in Korea, the Ministry of Food and Drug Safety has approved the use of AI-based medical devices since 2018.

However, there are still many concerns regarding AI-based medical technology owing to how different AI-based health care technologies are from traditional health care technologies; thus, the number of actual clinical treatment implementations using AI is still limited.^{12,13} To introduce and implement the AI technology in the actual medical site and to provide meaningful outcomes to the people involved in health care, including doctors and patients, various challenges need to be addressed. Therefore, this study discusses the status of the current developments in domestic and foreign AI technology in health care and examines the issues that need to be resolved to implement AI in health care.

AI APPLICATION AREAS IN HEALTH CARE

Unlike the typical technologies that deal with physical realms, AI technology is breaking new ground, as it has implications in more psychological realms such as experience, intelligence, and judgment of the experts. In particular, since the drastic improvement in the performance of machine learning algorithms for pattern recognition with the introduction of deep learning technology, the ability of AI technology in analyzing data patterns has become similar to that of an average human ability for specific tasks (e.g., image recognition and speech recognition).¹⁴ As deep learning algorithms are based on artificial neural network resembling the network of neurons in the human brain and can learn very complex non-linear relationships, they are being actively used in the tasks dealing with medical data.¹⁵ Accordingly, a number of studies on the use of AI-based technologies in health care are currently being conducted (Table 1).

Medical image analysis

In addition to radiology, the use of machine learning algorithms in medical image analysis has been expanded widely to most medical departments that use images for fields such as pathology, dermatology, cardiology, gastroenterology, and ophthalmology. In detail, machine learning algorithms use computed tomography (CT), magnetic resonance imaging, ultrasound, pathology image, fundus image, and endoscope data to diagnose or classify the severity of the disease.^{8,16-22} When the machine learning algorithm was applied to the real-time colonoscopy, the accuracy of the diagnosis was 94% and the negative predictive value was 96% in analyzing 466 tiny polyps.^{23,24} Among the many deep learning algorithms, the convolutional neural network algorithm, which retains high performance in image pattern analysis, has proven to be beneficial in analyzing medical images with complex patterns.^{4,25}

In the medical industry, Siemens Healthineers has developed AI-based AI-Rad Companion Chest CT software to assist chest CT diagnosis²⁶, and GE Healthcare is also working on the development of AI-based medical image analysis technology. Further, Philips Healthcare has developed IntelliSpace Discovery, an open platform for AI development and deployment,²⁷ and is working to commercialize its IntelliSite Pathology Solution in the digital pathology diagnosis field.²⁷ Arterys has received FDA clearance on its Cardio AI, Liver AI, and Lung AI software to establish Medical Imaging Cloud AI platform.²⁸ Apart from the abovementioned examples, various companies, such as Zebra Medical Vision and Aidoc, are working to commercialize

Table 1. Current applications of artificial intelligence in health care

Technology	Application scheme	Application area
Robotics	Provide high-quality treatment by improving the precision and accuracy of the surgical procedures.	Medical device, Health IT
Digital secretary	Find the golden hour of appropriate intervention by continuously monitoring the patient condition indicators and alerting the nurse when necessary.	Medical device, Health IT
Machine learning	Predict and analyze patterns based on the data affecting treatment results. Reduce the uncertainty in the medical treatment decision-making by processing large volumes of diagnostic medical images through self-learning.	Diagnostic medical image, Health IT
Image processing	Quickly process large amounts of medical images and apply the findings in judging the disease type and negative and positive test results.	Diagnostic medical image, Health IT
Natural language processing	Convert long unstructured text data, such as medical charts, to be easily read and interpreted.	Medical device, Health IT
Voice recognition	Capture patient voice and language and store important information in electronic medical records.	Medical device, Health IT
Statistical analysis	Predict patient treatment results through rapidly analyzing large amounts of patient health record data.	Medicine, Health IT
Big data analysis	Provide personalized recommendations to the patients and therapeutics by processing large amounts of data maintained by healthcare institutions.	Medicine, Health IT
Predictive modeling	Predict treatment outcomes, such as predicting risky diseases, by applying mathematical models.	Medicine, Health IT

IT = information technology.

AI-based medical image analysis tools. In Korea, a number of startups such as Vuno, Lunit, JLK Inspection, and Deepnoid are in the process of commercializing AI-based medical image analysis systems by receiving approval from the Ministry of Food and Drug Safety.

Smart IoT devices, signal, and in-vitro diagnostic analysis

Various technology giants such as IBM, Google, Apple, and Samsung are competing to develop and commercialize devices and services that can assist in improving the user health by acquiring health information from daily life using a combination of Internet of Things (IoT) technologies and wearable devices. In 2017, Apple installed a deep learning algorithm that detects atrial fibrillation on their smartwatch and received FDA approval.²³ Using the photoplethysmography and accelerometer sensors, it learns the user's usual heart rates at rest and at activity, and sends a warning sign if there is a significant difference from the expected values. The deep learning algorithm also shows excellent accuracy in analyzing electrocardiogram (ECG). In a recent study, 91,232 single-lead ECGs were analyzed using a deep learning algorithm and showed high diagnostic performance similar to those of cardiologists.²⁹ Applying the ECG pattern analysis algorithm to smart devices would be especially useful for patients with cardiovascular disease or chronic kidney disease with high blood potassium levels.

Global companies are developing other innovative medical devices as well, including non-invasive glucose meters.^{30,31} Such bio-signal monitoring devices can be used for disease management and treatment in different hospital environments, such as intensive care unit, operating room, emergency room, and recovery room, in addition to being used for predicting and diagnosing diseases based on the accumulated real-time information. One prime example of this is the collaboration between Medtronic and IBM in developing Sugar.IQ by combining Medtronic's continuous glucose monitoring and IBM's AI Watson.³² The Sugar.IQ has been proven to directly help diabetic patients by reducing the number of hypoglycemia and hyperglycemia symptoms.³³ In addition, PhysiQ's pinpointIQ device, which recently received the FDA approval, helps in preparing for sudden and fatal situations by continuously measuring the patient conditions from the wearable biosensors and by detecting subtle changes in the conditions.³⁴ Philips has also commercialized its Connected Care Solutions, which is an IT solution that enables the medical staff to monitor the patient conditions from anywhere including the emergency room, recovery room, and nurses station, through tablet PCs and smartphones.³⁵ Meanwhile, findings from studies that reported improvement in diagnosis sensitivity and specificity by applying machine learning to the multi-biomarker analysis have been used in real-world cases to classify the cancer-related biomarkers; moreover, machine learning has been applied in cases of in-vitro diagnosis of diseases such as tuberculosis and dementia.³⁶⁻³⁹

AI using electronic medical records (EMRs)

Currently, various attempts are actively being made to develop AI systems using EMRs. In the U.S., EMR companies including Allscripts, Athenahealth, Cerner, eClinicalWorks, and Epic are conducting research on optimizing hospital treatment processes using AI technology.⁴⁰ In Korea, EvidNet is working to develop multi-hospital clinical big data analysis technology based on observational health data sciences and informatics and common data model (CDM).^{41,42} Further, IBM has developed Watson for Oncology, which provides optimal personalized treatments for cancer patients, and its clinical trials are underway.⁴³ As for the Korean companies, Selvas AI and Linewalks are conducting similar studies.

CURRENT ISSUES OF AI IN HEALTH CARE

Issues of utilizing health care data

In most cases, health care data typically include personal identification information such as personal code, number, text, voice, sound, and image. To create a data-driven AI medical device, a large amount of these data carrying sensitive personal information are required, but obtaining such sensitive information may lead to legal issues regarding personal privacy.⁴⁴⁻⁴⁶ The widespread use of wireless AI devices in health care requires a new technologies such as IoT and cloud computing, which enables to deal with the processing and storage limitations in such devices.⁴⁷ However, cloud-assisted AI devices can give rise to serious security concerns to the private health care data. To solve this issue, technical research and attempts to change laws and regulations are in progress. In terms of technical research, various encryption technologies and de-identification or anonymization technologies of removing identity information are being developed. A popular example is the CDM-based distributed research network, which has recently received considerable attention in Korea.⁴⁸ Furthermore, a number of privacy-preserving data mining technologies such as the federated learning and homomorphic encryption have been developed in the U.S.^{49,50}

Many countries worldwide are currently forming institutional and legal systems to address the conflicting interests between the use of health care information and the protection of personal information. In the U.S., the Health Insurance Portability and Accountability Act (HIPAA) established in 1996 has given individuals the data rights for medical information copies, and the Blue Button system has been established to allow individuals to diversify the use of data through viewing their own personal health records online. According to the HIPAA guidelines, anonymization on 18 identifiers of protected health information has been established to efficiently facilitate the use of health data.⁵¹ In addition, through the enactment of the Health Information Technology for Economic and Clinical Health Act (HITECH Act) in 2009, an electronic health record has been developed and promoted to increase the interoperability of medical information between hospitals.⁵² Furthermore, the Centers for Medicare & Medicaid has launched the MyHealthEData and Blue Button 2.0 services in 2018 to enable patients to access and control their medical records and other health data. In Europe, through the General Data Protection Regulation established in 2016, the basic individual rights for personal information have been reinforced by mandating the EU members to protect personal information in accordance with the six data protection principles.⁵³ In Korea, efforts have been made in recent years to promote research on big data by providing rights to collect and use health care data based on the revision of the Bioethics and Safety Act. However, despite these efforts from many countries, no country has been able to systematically resolve the privacy issues regarding health care data.

Regulatory affairs and policies for new devices

Most AI-based medical devices exist in the form of software, and they are generally new devices different from the traditional devices in terms of regulatory affairs. Hence, new policies need to be established to approve and regulate such devices. The International Medical Device Regulators Forum has categorized these AI software intended to be used for medical purposes as “Software as a Medical Device (SaMD)”.⁵⁴ In the U.S., the Digital Health Unit was established by the FDA's Center for Devices and Radiological Health in May 2017 to promote the expertise in digital health care device approvals and regulations, and the FDA has announced the guidelines for SaMD in December 2017.⁵⁵ The FDA acknowledges that the current regulations for traditional medical devices are not suitable for SaMDs that are faster

in development and modification.⁵⁶ FDA has recently developed a Software Precertification Program, which enables faster marketing of SaMD through a developer-centered certification pathway unlike the existing pathway centered on individual products. Manufacturers who achieved ‘organizational excellence’ in this pathway can obtain exemption from premarket review for low-risk products. Japan, in accordance with the AI medical development plans announced in 2018, is planning to create comprehensive rules governing the use of AI in medical devices to minimize the existing AI medical device–related disputes and prevent the resulting R&D hinderances.⁵⁷ Lastly in Korea, the “Approval and Review Guidelines for Big Data and AI-based Medical Devices” and “Review Guidelines for Clinical Effectiveness of AI-based Medical Devices” were announced in 2017, making them some of the first AI-related approval guidelines in the world.⁵⁸ However, the standardized review index for the safety and effectiveness of the AI-based medical devices is still lacking worldwide.⁴

Safety and liability issues

The report on AI published by the U.S. National Science and Technology Council emphasizes on the fairness and safety to prevent any discrimination or failure and to prevent AI from causing unintended consequences (Fig. 1).^{59,60} For example, if the AI is developed to have a bias toward a specific population group, a mismanagement could occur in the prevention or diagnosis of a disease and thus discrimination could arise in which a specific population group is excluded from benefits. To address this, the federal government is promoting verification of the effectiveness and fairness of AI through the evidence-based assessment, and the federal government funding for research is mandated to be allocated based on the transparency, effectiveness, and fairness. Furthermore, the government is recommending the universities and secondary schools to include topics related to ethics, safety, and privacy in the AI or data science curriculum. The council has also highlighted the cyber security related to AI and emphasized on establishing responsible strategies and plans at a federal level, including R&D for the sustainable security system development and operation in response to cyberattacks.

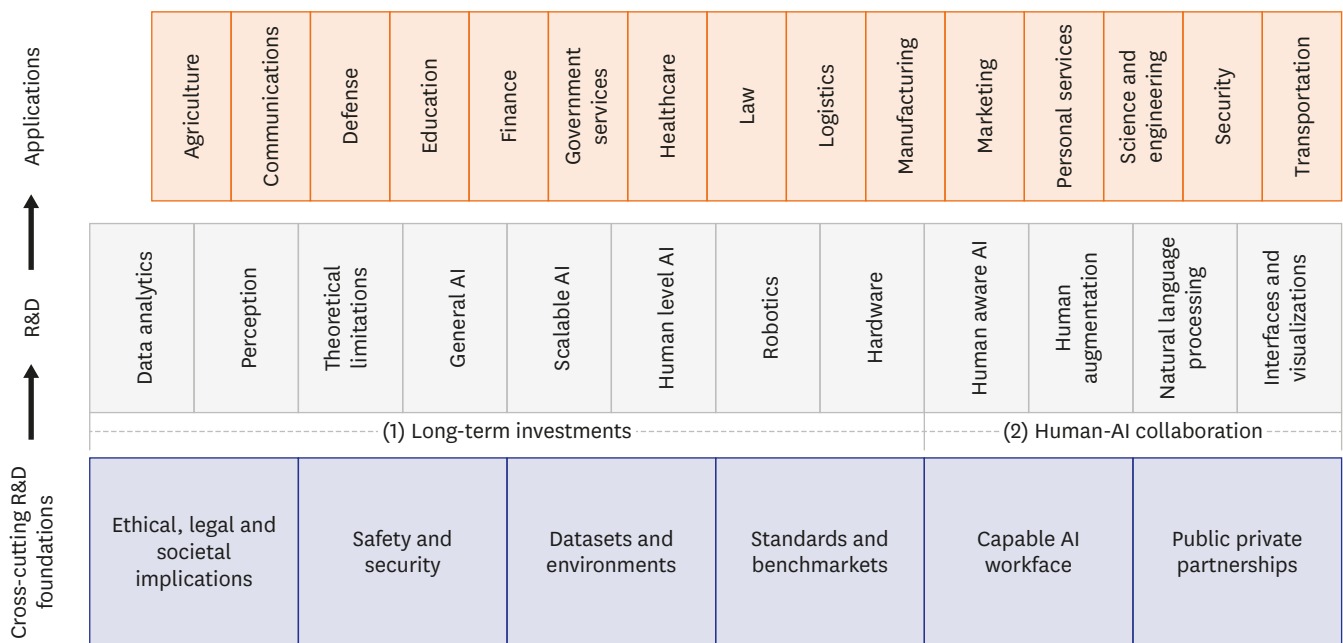


Fig. 1. Research and development strategic plan of artificial intelligence.⁶⁰ AI = artificial intelligence.

The present health care system assumes that all responsibility lies in the hands of the medical staff in the event of a medical accident. The AI-based medical technology may affect the judgment of physicians in various areas and may sometimes cause negative impacts, resulting in medical accidents. In such cases, liability issues would arise, and in the current health care system, it is highly likely that the medical institution or physicians who ultimately introduced the AI-based medical technology would be responsible for the case. Hence, physicians need to learn how to better utilize and interpret AI algorithms and be aware of potential legal consequences associated with AI use in medical practice.⁶¹ In addition, efforts in academia and policymaking should be made to straighten the liability issues and to evaluate the medical accident risks based on the various characteristics of AI technologies.⁶² Specifically, new policies should be introduced for the establishment and operation of the AI monitoring centers in medical institutions and a national level safety monitoring center for monitoring the safety of the AI-based medical technologies. In addition, a system for measuring the liability and strengthening the awareness of patients and medical staff on medical accidents that may take place when applying the AI-based medical technologies should be established.

Balanced application with existing health care systems

Applying a newly developed AI technology to real-world health care service can lead to unexpected problems. Therefore, the introduction of AI devices should be in harmony with existing health care systems, and the performance of AI devices must be monitored periodically. It is also important that AI devices should be easy to use and familiar to medical staff and patients to avoid any misunderstandings and errors when making medical decisions.

As the AI technology in its nature mainly relies on data, performance changes may be found when the pre-applied AI technology is retrained with the desired field data. This change may not always result in a performance improvement; rather it may result in a performance degradation.⁶³ In addition, the AI device performances may vary when the distribution or severity of patients in the institution changes depending on the differences in social, economic, and medical environments. Although the current laws and regulations in Korea do not allow the use of field data in improving the AI device performances, considering the nature of the technology, retraining using field data could be approved in the near future provided certain conditions are fulfilled. Accordingly, the performance of AI devices should be periodically checked even after the clinical application to prevent any unexpected performance degradation or malfunction.

Considering the importance and complexity of the modern health care field, the AI technology should be applied to health care as naturally and seamlessly as possible without causing excessive changes in the current medical practices. For this reason, it is necessary to implement the interaction and interface technologies that can enable the medical staff to apply AI technology to the medical field in a natural way even if they do not directly understand the technical aspects of the AI devices. These technologies can be implemented in the form of conversational AI, voice recognition, real-time recommendation, monitoring, and various visual overlay technologies. At the same time, careful considerations should be given to these user interface elements when developing and integrating AI technologies into health care.

CONCLUSIONS

AI technologies are expected to bring innovations to the existing medical technologies and future health care. The currently available AI-based health care technologies have shown outstanding results in accurately diagnosing and classifying patient conditions and predicting the course of diseases by using the accumulated medical data. Accordingly, these technologies are expected to bring contributions in assisting the medical staff in the treatment decision-making and in the process improving the treatment results. However, AI-based health care technologies currently have various issues regarding privacy, reliability, safety, and liability. For the AI technologies to be more actively applied in health care, general public awareness of AI, establishment of standardized guidelines, and systematic improvements will be required in the future in addition to the technological advancements.

ACKNOWLEDGMENTS

The content of this article is the official opinion of the Korean Society of Artificial Intelligence in Medicine (KOSAIM), and is a summary of the White Paper on Artificial Intelligence in Medicine. The authors would like to thank all the members of KOSAIM for their supports in the publication of this article.

REFERENCES

1. Rajkumar A, Dean J, Kohane I. Machine learning in medicine. *N Engl J Med* 2019;380(14):1347-58.
[PUBMED](#) | [CROSSREF](#)
2. Shimizu H, Nakayama KI. Artificial intelligence in oncology. *Cancer Sci* 2020;111(5):1452-60.
[PUBMED](#) | [CROSSREF](#)
3. Obermeyer Z, Emanuel EJ. Predicting the future - big data, machine learning, and clinical medicine. *N Engl J Med* 2016;375(13):1216-9.
[PUBMED](#) | [CROSSREF](#)
4. Jiang F, Jiang Y, Zhi H, Dong Y, Li H, Ma S, et al. Artificial intelligence in healthcare: past, present and future. *Stroke Vasc Neurol* 2017;2(4):230-43.
[PUBMED](#) | [CROSSREF](#)
5. Cruz JA, Wishart DS. Applications of machine learning in cancer prediction and prognosis. *Cancer Inform* 2007;2:59-77.
[PUBMED](#)
6. Ryu SM, Seo SW, Lee SH. Novel prognostication of patients with spinal and pelvic chondrosarcoma using deep survival neural networks. *BMC Med Inform Decis Mak* 2020;20(1):3.
[PUBMED](#) | [CROSSREF](#)
7. 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(1):35.
[PUBMED](#) | [CROSSREF](#)
8. Ting DS, Cheung CY, Lim G, Tan GS, Quang ND, Gan A, et al. Development and validation of a deep learning system for diabetic retinopathy and related eye diseases using retinal images from multiethnic populations with diabetes. *JAMA* 2017;318(22):2211-23.
[PUBMED](#) | [CROSSREF](#)
9. Han I, Kim JH, Park H, Kim HS, Seo SW. Deep learning approach for survival prediction for patients with synovial sarcoma. *Tumour Biol* 2018;40(9):1010428318799264.
[PUBMED](#) | [CROSSREF](#)
10. Lee J, An JY, Choi MG, Park SH, Kim ST, Lee JH, et al. Deep learning-based survival analysis identified associations between molecular subtype and optimal adjuvant treatment of patients with gastric cancer. *JCO Clin Cancer Inform* 2018;2(2):1-14.
[PUBMED](#) | [CROSSREF](#)

11. Kim JK, Choi MJ, Lee JS, Hong JH, Kim CS, Seo SI, et al. A Deep Belief Network and Dempster-Shafer-Based Multiclassifier for the Pathology stage of prostate cancer. *J Healthc Eng* 2018;2018:4651582.
[PUBMED](#) | [CROSSREF](#)
12. The Lancet. Artificial intelligence in health care: within touching distance. *Lancet* 2018;390(10114):2739.
[PUBMED](#)
13. Kelly CJ, Karthikesalingam A, Suleyman M, Corrado G, King D. Key challenges for delivering clinical impact with artificial intelligence. *BMC Med* 2019;17(1):195.
[PUBMED](#) | [CROSSREF](#)
14. Erickson BJ, Korfiatis P, Akkus Z, Kline TL. Machine learning for medical imaging. *Radiographics* 2017;37(2):505-15.
[PUBMED](#) | [CROSSREF](#)
15. Hu W, Cai B, Zhang A, Calhoun VD, Wang YP. Deep collaborative learning with application to the study of multimodal brain development. *IEEE Trans Biomed Eng* 2019;66(12):3346-59.
[PUBMED](#) | [CROSSREF](#)
16. Patel V, Armstrong D, Ganguli M, Roopra S, Kantipudi N, Albashir S, et al. Deep learning in gastrointestinal endoscopy. *Crit Rev Biomed Eng* 2016;44(6):493-504.
[PUBMED](#) | [CROSSREF](#)
17. Komura D, Ishikawa S. Machine learning approaches for pathologic diagnosis. *Virchows Arch* 2019;475(2):131-8.
[PUBMED](#) | [CROSSREF](#)
18. Currie G, Hawk KE, Rohren E, Vial A, Klein R. Machine learning and deep learning in medical imaging: intelligent imaging. *J Med Imaging Radiat Sci* 2019;50(4):477-87.
[PUBMED](#) | [CROSSREF](#)
19. 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. *JAMA* 2016;316(22):2402-10.
[PUBMED](#) | [CROSSREF](#)
20. Ting DS, Pasquale LR, Peng L, Campbell JP, Lee AY, Raman R, et al. Artificial intelligence and deep learning in ophthalmology. *Br J Ophthalmol* 2019;103(2):167-75.
[PUBMED](#) | [CROSSREF](#)
21. Park HJ, Kim SM, La Yun B, Jang M, Kim B, Jang JY, et al. A computer-aided diagnosis system using artificial intelligence for the diagnosis and characterization of breast masses on ultrasound: added value for the inexperienced breast radiologist. *Medicine (Baltimore)* 2019;98(3):e14146.
[PUBMED](#) | [CROSSREF](#)
22. Kim K, Kim S, Lee YH, Lee SH, Lee HS, Kim S. Performance of the deep convolutional neural network based magnetic resonance image scoring algorithm for differentiating between tuberculous and pyogenic spondylitis. *Sci Rep* 2018;8(1):13124.
[PUBMED](#) | [CROSSREF](#)
23. Topol EJ. High-performance medicine: the convergence of human and artificial intelligence. *Nat Med* 2019;25(1):44-56.
[PUBMED](#) | [CROSSREF](#)
24. Mori Y, Kudo SE, Misawa M, Saito Y, Ikematsu H, Hotta K, et al. Real-time use of artificial intelligence in identification of diminutive polyps during colonoscopy: a prospective study. *Ann Intern Med* 2018;169(6):357-66.
[PUBMED](#) | [CROSSREF](#)
25. Soffer S, Ben-Cohen A, Shimon O, Amitai MM, Greenspan H, Klang E. Convolutional neural networks for radiologic images: a radiologist's guide. *Radiology* 2019;290(3):590-606.
[PUBMED](#) | [CROSSREF](#)
26. Fischer AM, Varga-Szemes A, Martin SS, Sperl JI, Sahbaee P, Neumann D, et al. Artificial intelligence-based fully automated per lobe segmentation and emphysema-quantification based on chest computed tomography compared with global initiative for chronic obstructive lung disease severity of smokers. *J Thorac Imaging* 2020;35 Suppl 1:S28-34.
[PUBMED](#) | [CROSSREF](#)
27. Philips. IntelliSpace discovery. <https://www.usa.philips.com/healthcare/product/HC881015/intellispace-discovery>. Updated 2020. Accessed August 19, 2020.
28. WELCOMEAI. Arterys - Cardio AI. <https://www.welcome.ai/tech/healthcare/arterys-cardio-ai>. Updated 2020. Accessed August 19, 2020.
29. Hannun AY, Rajpurkar P, Haghpanahi M, Tison GH, Bourn C, Turakhia MP, et al. Cardiologist-level arrhythmia detection and classification in ambulatory electrocardiograms using a deep neural network. *Nat Med* 2019;25(1):65-9.
[PUBMED](#) | [CROSSREF](#)

30. Vahlsing T, Delbeck S, Leonhardt S, Heise HM. Noninvasive monitoring of blood glucose using color-coded photoplethysmographic images of the illuminated fingertip within the visible and near-infrared range: opportunities and questions. *J Diabetes Sci Technol* 2018;12(6):1169-77.
[PUBMED](#) | [CROSSREF](#)
31. Fernández-Caramés TM, Froiz-Míguez I, Blanco-Novoa O, Fraga-Lamas P. Enabling the internet of mobile crowdsourcing health things: a mobile fog computing, blockchain and IoT based continuous glucose monitoring system for diabetes mellitus research and care. *Sensors (Basel)* 2019;19(15):E3319.
[PUBMED](#) | [CROSSREF](#)
32. Mobihealthnews. Medtronic, IBM Watson launch Sugar.IQ diabetes assistant. <https://www.mobihealthnews.com/content/medtronic-ibm-watson-launch-sugariq-diabetes-assistant>. Updated 2018. Accessed August 19, 2020.
33. 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.
[PUBMED](#) | [CROSSREF](#)
34. PhysIQ. PinpointIQ. <https://www.physiq.com/solutions/pinpointiq/>. Updated 2020. Accessed August 19, 2020.
35. Philips. Connected care solutions. <http://www.thinkconnectedcare.philips.com/en.aspx>. Updated 2020. Accessed August 19, 2020.
36. Ahmed MR, Zhang Y, Feng Z, Lo B, Inan OT, Liao H. Neuroimaging and machine learning for dementia diagnosis: recent advancements and future prospects. *IEEE Rev Biomed Eng* 2019;12:19-33.
[PUBMED](#) | [CROSSREF](#)
37. Kim JP, Kim J, Park YH, Park SB, Lee JS, Yoo S, et al. Machine learning based hierarchical classification of frontotemporal dementia and Alzheimer's disease. *Neuroimage Clin* 2019;23:101811.
[PUBMED](#) | [CROSSREF](#)
38. Beccaria M, Mellors TR, Petion JS, Rees CA, Nasir M, Systrom HK, et al. Preliminary investigation of human exhaled breath for tuberculosis diagnosis by multidimensional gas chromatography - time of flight mass spectrometry and machine learning. *J Chromatogr B Analyt Technol Biomed Life Sci* 2018;1074-1075:46-50.
[PUBMED](#) | [CROSSREF](#)
39. Long NP, Jung KH, Yoon SJ, Anh NH, Nghi TD, Kang YP, et al. Systematic assessment of cervical cancer initiation and progression uncovers genetic panels for deep learning-based early diagnosis and proposes novel diagnostic and prognostic biomarkers. *Oncotarget* 2017;8(65):109436-56.
[PUBMED](#) | [CROSSREF](#)
40. Healthcare IT News. Next up for EHRs: vendors adding artificial intelligence into the workflow. <https://www.healthcareitnews.com/news/next-ehrs-vendors-adding-artificial-intelligence-workflow>. Updated 2018. Accessed August 20, 2020.
41. EvidNet. <https://en.evidnet.com/>. Updated 2020. Accessed August 20, 2020.
42. Hripcsak G, Duke JD, Shah NH, Reich CG, Huser V, Schuemie MJ, et al. Observational health data sciences and informatics (OHDSI): opportunities for observational researchers. *Stud Health Technol Inform* 2015;216:574-8.
[PUBMED](#)
43. IBM. Clinical trial recruitment with AI. <https://www.ibm.com/watson-health/learn/clinical-trial-recruitment>. Updated 2020. Accessed August 20, 2020.
44. Azencott CA. Machine learning and genomics: precision medicine versus patient privacy. *Philos Trans A Math Phys Eng Sci* 2018;376(2128):20170350.
[PUBMED](#) | [CROSSREF](#)
45. Mooney SJ, Pejaver V. Big data in public health: terminology, machine learning, and privacy. *Annu Rev Public Health* 2018;39(1):95-112.
[PUBMED](#) | [CROSSREF](#)
46. Kayaalp M. Patient privacy in the era of big data. *Balkan Med J* 2018;35(1):8-17.
[PUBMED](#) | [CROSSREF](#)
47. Sajid A, Abbas H. Data privacy in cloud-assisted healthcare systems: state of the art and future challenges. *J Med Syst* 2016;40(6):155.
[PUBMED](#) | [CROSSREF](#)
48. You SC, Lee S, Cho SY, Park H, Jung S, Cho J, et al. Conversion of National Health Insurance Service-national sample cohort (NHIS-NSC) database into observational medical outcomes partnership-common data model (OMOP-CDM). *Stud Health Technol Inform* 2017;245:467-70.
[PUBMED](#)
49. Aldeen YA, Salleh M, Razzaque MA. A comprehensive review on privacy preserving data mining. *Springerplus* 2015;4(1):694.
[PUBMED](#) | [CROSSREF](#)

50. Lee J, Sun J, Wang F, Wang S, Jun CH, Jiang X. Privacy-preserving patient similarity learning in a federated environment: development and analysis. *JMIR Med Inform* 2018;6(2):e20.
[PUBMED](#) | [CROSSREF](#)
51. Tariq RA, Hackert PB. *Patient Confidentiality*. Treasure Island, FL: StatPearls Publishing LLC.; 2020.
52. Pipersburgh J. The push to increase the use of EHR technology by hospitals and physicians in the United States through the HITECH Act and the Medicare incentive program. *J Health Care Finance* 2011;38(2):54-78.
[PUBMED](#)
53. John B. Are you ready for general data protection regulation? *BMJ* 2018;360:k941.
[PUBMED](#) | [CROSSREF](#)
54. Pelayo S, Bras Da Costa S, Leroy N, Loiseau S, Beuscart-Zephir MC. Software as a medical device: regulatory critical issues. *Stud Health Technol Inform* 2013;183:337-42.
[PUBMED](#)
55. U.S. Food and Drug Administration. Software as a Medical Device (SaMD). <https://www.fda.gov/medical-devices/digital-health/software-medical-device-samd>. Updated 2018. Accessed August 20, 2020.
56. He J, Baxter SL, Xu J, Xu J, Zhou X, Zhang K. The practical implementation of artificial intelligence technologies in medicine. *Nat Med* 2019;25(1):30-6.
[PUBMED](#) | [CROSSREF](#)
57. Nikkei Asian. New rules to speed AI-based medicine in Japan. <https://asia.nikkei.com/Economy/New-rules-to-speed-AI-based-medicine-in-Japan>. Updated 2018. Accessed August 20, 2020.
58. The Korea Industry Daily. <http://www.kidd.co.kr/news/198013>. Updated 2017. Accessed August 20, 2020.
59. Executive Office of the President (US). Artificial intelligence, automation, and the economy. <https://www.whitehouse.gov/sites/whitehouse.gov/files/images/EMBARGOED%20AI%20Economy%20Report.pdf>. Updated 2016. Accessed August 20, 2020.
60. Executive Office of the President (US). The national artificial intelligence research and development strategic plan: 2019 update. <https://www.nitrd.gov/pubs/National-AI-RD-Strategy-2019.pdf>. Updated 2019. Accessed August 20, 2020.
61. Price WN 2nd, Gerke S, Cohen IG. Potential liability for physicians using artificial intelligence. *JAMA* 2019;322(18):1765.
[PUBMED](#) | [CROSSREF](#)
62. Reed C. How should we regulate artificial intelligence? *Philos Trans A Math Phys Eng Sci* 2018;376(2128):20170360.
[PUBMED](#) | [CROSSREF](#)
63. Veeranki SP, Kramer D, Hayn D, Jauk S, Eggerth A, Quehenberger F, et al. Is regular re-training of a predictive delirium model necessary after deployment in routine care? *Stud Health Technol Inform* 2019;260:186-91.
[PUBMED](#)