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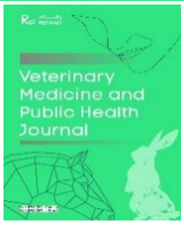
Veterinary Medicine and Public Health Journal (VMPH)

Journal Homepage: https://www.refaad.com/Journal/Index/7

E-ISSN 2707-7195 | P-ISSN 2707-7187

Vol. 6, No. 3, 2025, pp. 105 - 118



Artificial Intelligence in Medicine and Sustainable Development

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Review Article
https://doi.org/10.31559/VMPH2025.6.3.4
Received: 10 Dec 2024
Revised: 8 June 2025
Accepted: 28 Sept 2025

How to cite this article: Alfouri, A., & Alfouri, S. (2025). Artificial Intelligence in Medicine and Sustainable Development. *Veterinary Medicine and Public Health Journal*, 6 (3), 105-118. https://doi.org/10.31559/VMPH2025.6.3.4

Abstract:
Objectives: The purpose of this paper is to explore the role of artificial intelligence (AI) in advancing modern healthcare while addressing its alignment with sustainable development goals. The study aims to highlight both the benefits of AI applications in medicine and the challenges associated with their ethical use, data privacy, and environmental impact.
Methods: This paper adopts a qualitative review approach, synthesizing recent literature and case studies related to AI in disease detection, medical imaging, clinical trials, and drug development. It compares the advantages of AI systems over traditional methods and evaluates their implications for healthcare delivery, sustainability, and policy.
Results: Findings indicate that AI enhances diagnostic speed and accuracy, supports drug discovery efficiency, and improves healthcare accessibility. However, limitations such as data scarcity for rare diseases, potential biases in algorithms, and high energy consumption remain significant challenges. Real-world examples, including biased dermatology algorithms and AI-enabled imaging tools, illustrate both the transformative potential and risks of AI.
Conclusion: AI has the capacity to revolutionize healthcare if guided by ethical frameworks, sustainable practices, and robust governance. Practical steps such as adopting federated learning to safeguard data privacy and investing in green AI technologies can ensure responsible innovation.

Keywords: *Artificial Intelligence; Healthcare; Sustainable Development; Medical Imaging; Ethics; Data Privacy.*

1 Introduction

It can be said that emerging computer-based technologies are growing exponentially. Digital healthcare provides many opportunities to reduce human error, improve clinical outcomes, and track data over time. AI methods, including machine learning (ML) and deep learning (DL) algorithms, are widely used in predicting and diagnosing many diseases, especially those whose diagnosis is based on imaging or signal analysis (Abbaoui et al. 2024; Adigweet al. 2024). Artificial intelligence can also help identify demographics or environmental areas where diseases or high-risk behaviors are prevalent. For example, facial recognition is also achieved through a process consisting of an encoder and a decoder, where the encoder compresses the input facial image vector x into a lower-dimensional space, while the decoder reconstructs it into its original form (Solomon et al.,2023).

Human intelligence is completely different from artificial intelligence. Human intelligence refers to the sum of many cognitive abilities including abstract reasoning, problem solving, communication, learning, and understanding. Human intelligence and artificial intelligence differ fundamentally, but in healthcare, the relevance lies less in philosophical contrasts and more in practical applications. Unlike human intelligence, which is shaped by emotions, creativity, and social context, AI in medicine provides measurable benefits such as speed, scalability, and accuracy. For instance, AI systems can process thousands of radiological images within minutes, identify hidden patterns in genetic data, and assist in early disease detection—advantages that go far beyond the human capacity for manual analysis. Thus, rather than focusing on abstract comparisons, this paper emphasizes the healthcare-specific advantages of AI and its growing role in supporting clinicians and improving patient outcomes. (Monteith et al.,2024).

Generative Artificial intelligence (GenAI) is a technology that autonomously produces new original outputs based on the large-scale multimodal input data it has been trained on. These include text, images, speech, video, symbols, molecular structures, chemical data, and other types of data (He et al. ,2023). GenAI is a subset of the broader Artificial intelligence umbrella that enables computers to learn from the structures and patterns inherent in data, enabling subsequent decision-making (Figure 1) (Deeb et al., 2024).

Deep learning (DL) is a more complex iteration of machine learning (ML), inspired by the architecture of the human brain, using layers of neural networks to assimilate and learn from large amounts of data. Large language models (LLMs) are products of deep learning and can understand and create texts like humans. These LLMs use natural language processing (NLP), a field at the intersection of computer science, artificial intelligence, and linguistics that enable computers to understand, interpret, and generate human language in a meaningful and useful way. GenAI also has applications in the field of computer vision, where generative adversarial networks (GANs) have been implemented to generate many forms of medical images, ranging from pathology slides to ultrasound and MRI (Shorten et al.,2019). Conversely, discriminative AI models (sometimes referred to as predictive models) classify data, predicting labels based on the information provided (Deeb et al., 2024).

As deep learning models scale to large datasets - in part because they can run on specialized computing hardware - they continue to improve with more data, enabling them to outperform many classical machine learning approaches. Deep learning systems can also accept multiple types of data as input - an aspect of particular importance for heterogeneous healthcare data. The most common models are trained using supervised learning, where datasets consist of input data points (e.g., images of skin lesions) and corresponding output data labels (e.g., "benign" or "malignant") (Sarojini et al.,2020). Reinforced learning (RL), where computational agents learn by trial and error or through expert demonstration (Grzybowski et al ,2024), has advanced with the adoption of deep learning, achieving remarkable achievements. RL can be useful in healthcare when learning requires demonstration by a physician, for example in learning how to suture wounds in robot-assisted surgeries (Esteva et al ,2019; Morris et al.,2024). Machine vision, coupled with artificial intelligence, enables robotic systems to interpret images during surgery in real time, ensuring precise navigation, tissue identification, and execution of surgical tasks. Moreover, predictive modeling and decision support systems for personalized surgery play a crucial role in personalized surgery by predicting potential complications and recommending optimal surgical approaches tailored to individual patient characteristics. These models enhance the accuracy of surgical interventions and reduce the risk of adverse outcomes.

The convolutional neural network can be defined as a special type of feed forward neural network that derives its inspiration from the biological processes that occur in the optic lobe specifically in the brain of living organisms; is considered a solution to many computer vision problems in artificial intelligence such as image and video processing (Alowais et al, 2023 ;Le Brigant et al, 2021). It is a successful approach to image analysis and classification and is a supervised deep learning model. It consists of fully connected layers with standard weights that result in fewer parameters for training features through the backpropagation process. It is designed to extract spatial information from input images and aims to learn hierarchical features adaptively, classify image data, and extract their features automatically. The main advantage of this algorithm is to learn highly abstract features with few parameters and simple preprocessing (Cheng et al, 2017). The initialization of the neural network and the order of samples during the training phase are usually random. However, when the training is over, nothing unexpected happens to the neural network.

Artificial intelligence methods go hand in hand with the Internet of Things (IoT) in the healthcare system in treatment procedures and healthcare technology (Ding et al., 2023; Salunke et al.,2024). A reliable IoT-based system using machine learning algorithms for healthcare is proposed to monitor human activities and the surrounding environment through a body sensor network (Bignami et al, 2024). Studies proposed a hybrid IoT model using healthcare monitoring system and random forest technique to predict type 2 diabetes (Thirunavukarasu et al.,2023; Alowais et al, 2023).

Fully Connected Neural Networks (FCNNS) consist of neurons and model layers, where the inputs of each layer are connected to each neuron in the layer below. The most straightforward way to understand neurons is to think of them as linear regression models, where each neuron uses data input (x), weights (y), and bias (z) to generate an output (y). If the result after the activation function is zero, the neuron in that state is removed. The value of the neuron must pass through the activation function. In any other case, the value will be sent to the next layer of the network. Depending on the type of activation function used, the output value changes. For example, the output of a sigmoid activation function will have an S-shaped curve and range between 0 and 1. The Rectified Linear Unit (ReLU) activation function is another example; for values greater than 0, it has a linear shape, while for values less than or equal to 0, it has a 0 (Zargar et al.,2023).

An important question is whether there is gender or racial bias in the images produced by Artificial intelligence programs such as ChatGPT. It can be said that many AI models generate images based on the data they were trained on. This data reflects the diversity, and biases present in cultural context and the broader internet (Morrow et al.,2023), which brings forth another important question on the gender and racial stereotypes that AI programs amplify.

Artificial intelligence models like DALL¢E can unintentionally amplify gender, and racial stereotypes present in the data they are trained on. These stereotypes are reflections of societal biases and historical representations in media, literature, and online content. The following are some examples of stereotypes that can be amplified (Grzybowski et al ,2024):

- Occupational stereotypes: Some occupations may be portrayed as male- or female-dominated. For example, technical roles may be portrayed as male characters; while caring or nurturing roles may feature primarily women.
- Racial stereotypes: Certain racial groups may be overrepresented in specific contexts, reinforcing narrow or stereotypical portrayals. For example, racial diversity may be underrepresented in professional or heroic roles (Currie et al, 2024).
- Cultural representation: Depictions of cultural elements may tend toward stereotypes, such as clothes or traditional roles, without reflecting the true diversity and modern aspects of those cultures.
- Physical appearance: Stereotypes related to beauty standards, body types, and physical attributes can be reinforced, such as the portrayal of idealized or exaggerated features based on gender or race.
- Activities and roles: The model may associate certain activities or roles with certain genders or ethnic groups, such as sports, hobbies, or household chores, based on stereotypes in the media (Currie et al, 2024).

The Effective Role of Artificial Intelligence Technologies in Identifying and Predicting Human Disorders and Diseases.

Learning algorithms and big data derived from medical records or devices are the most vital tools to efficiently implement Artificial intelligence methods in the healthcare system to improve disease diagnosis and classification, decision-making activities, performance of walking aids, provide optimal treatment options, and ultimately help people have safe and long lives (Abbaoui et al. 2024 ;Bignami et al, 2024). AI is used to improve medical analysis and diagnosis in a short time. For example, this technology can detect dangerous tumors in medical images allowing pathologists to diagnose and treat the disease at an early stage instead of sending tissue samples or lesions to the laboratory for long-term investigation (Alowais et al, 2023). AI-based algorithms are also an effective tool for identifying undiagnosed or underdiagnosed patients and uncoded and rare diseases. One of the main challenges in disease detection using AI is data scarcity, particularly for rare or underdiagnosed conditions. Reliable datasets are often limited, which hinders the training of robust models. In addition, data quality, labeling costs, and potential sampling biases pose further obstacles. Addressing these challenges requires strategies such as data augmentation, federated learning, and international collaboration to ensure diverse and representative datasets before implementing technical solutions. (Ibrahim et al., 2024).

In the field of surgical preparation, GenAI could revolutionize organ transplant procedures by facilitating the creation of 3D visualization models from 2D images, thereby improving the accuracy and efficiency of surgical planning for organ transplantation. GenAI can also improve education for transplant providers, from physicians to nurses and surgery coordinators, by creating personalized educational materials that target learners' levels, training backgrounds, and different knowledge gaps. Additionally, GenAI's ability to create realistic simulations holds promise for complex surgical training in organ transplantation (Deeb et al., 2024).

2 Challenges, Potential Solutions, and Prospects of AI Methods

Artificial intelligence plays a broad role in healthcare systems for diagnosis, prediction, and prevention purposes. However, there are several challenges in using deep learning and machine learning techniques in disease diagnosis and prediction. One significant challenge in AI algorithms is the need for massive data in the training phases, which is not always practical for most diseases. Another challenge is data labeling, which requires expertise, is time-consuming, and is very expensive. This can make it difficult to develop accurate models for rare or new diseases. One potential solution to the lack of labeled data is to use techniques such as data augmentation, which can be used to artificially increase the size of a dataset (Gupta and Pravir ,2023).

The computational and architectural complexity of deep learning-based models is another challenge in this field. One potential solution to reduce the computational and architectural complexity of deep learning models is to use model compression techniques such as pruning, quantization, and low-rank factorization. These techniques can help reduce the required number of parameters and computational resources while maintaining good performance. Analyzing low-contrast images is also a challenging task for examining patterns and features (Hu et al. ,2023). Histogram equalization is a technique used in digital image processing, where the image contrast is modified and its histogram is made as flat and distributed as possible. One of the enhancement techniques used to enhance contrast is to propose a supervised method by machine learning based on the selection of hyperparameters through HE technology to improve visual appearance and increase the image contrast while maintaining its natural aspect (Le Brigant et al, 2021). Other researchers have also proposed a new approach to enhance contrast based on HE in cancer diagnosis using medical ultrasound imaging. Medical image compression technology is also used to reduce the transmission bandwidth requirements and storage size (Paul et al.,2022). Moreover, ultrasound ECG images based on XGBoost algorithm enhancement have been adopted for screening and diagnosis of hypertensive patients during pregnancy in this field. The results found that XGBoost algorithm can obtain clearer and more accurate ECG images and data for patients quickly and effectively compared with normal healthy pregnant women (Zhang et al.,2022).

3 Results and Discussion

3.1 Artificial Intelligence Applications in Medicine

The future of "standard" medical practice may be closer than anticipated, where a patient might see a computer before seeing a doctor. With advancements in artificial intelligence, it seems possible that the days of misdiagnosis and treating symptoms rather than the underlying cause could soon be gone. While some algorithms can rival doctors and sometimes outperform them in a variety of tasks, they have not yet been fully integrated into daily medical practice because although these algorithms can significantly impact medicine and enhance the power of medical interventions, there are many regulatory concerns that need to be addressed first.

3.2 What makes an algorithm intelligent?

Like the way doctors learn through years of medical study, performing duties and practical tests, obtaining grades, and learning from mistakes, AI algorithms must also learn how to perform their tasks. In general, they can perform tasks that require human intelligence to complete, such as pattern and speech recognition, image analysis, and decision-making (Bignami et al, 2024). However, humans still need to explicitly tell the computer what exactly to look for in the image provided to the algorithm, for example. Thus, AI algorithms are great for automating tedious tasks and can sometimes outperform humans in tasks they have been trained to perform (Alowais et al, 2023; Hawk et al, 2024).

Recently, other imaging-based algorithms have shown similar potential to boost physician accuracy. In the short term, doctors could use these algorithms to help double-check their diagnoses and interpret patient data faster without sacrificing accuracy (Alowais et al, 2023). But in the long term, government-approved algorithms could operate autonomously in clinics, allowing doctors to focus on cases that computers can’t solve. LYNA and DLAD are prime examples of algorithms that complement doctors’ classifications of healthy and diseased specimens by highlighting salient features of images that should be studied more closely. These works illustrate the potential strengths of algorithms in medicine.

3.3 How to use artificial intelligence in medicine:

3.3.1 Artificial Intelligence in Disease Detection and Diagnosis

Unlike humans, AI never needs to sleep. Therefore, machine learning models can be used to monitor the vital signs of critically ill patients and alert doctors if certain risk factors increase. While medical devices such as heart monitors can track vital signs (Bignami et al, 2024), AI can collect data from those devices and look for more complex conditions, such as sepsis (sepsis is a potentially life-threatening condition caused by the body destroying its own tissues in response to an infection. When the body’s infection-fighting processes go awry, it can cause organs to stop functioning properly.) An IBM client has developed a predictive AI model for premature babies that is 75% accurate at detecting severe sepsis. Preterm birth is the birth of a baby at less than 37 weeks of gestation. These babies are known as premature babies.

Accurate diagnosis of diseases is crucial for treatment planning and ensuring patient’s well-being. However, human errors limit the accuracy and efficiency of diagnosis (Alowais et al, 2023), especially in general clinical practice and rural areas, where interpreting medical knowledge is a complex and cognitively challenging task. AI techniques, such as convolutional neural networks (Litjens et al.,2017), knowledge graphs, and transformers, have been validated as powerful and promising tools to help improve the diagnosis and even treatment of various diseases (Dreizin et al., 2023). Therefore, the application of AI within the diagnostic process supports medical professionals to improve the accuracy and efficiency of diagnosis and provide emerging digital healthcare services.

3.3.2 Treating diseases with the help of an AI-powered virtual assistant

Precision medicine could be made easier with the help of virtual AI. Because AI models can learn and retain preferences, AI has the potential to make personalized recommendations in real time to patients around the clock (Alowais et al, 2023). Thus, a new term has emerged: precision medicine or personalized medicine. That’s because even the world’s best scientists and doctors don’t yet fully understand how different people get sick and respond to treatments. The result is a “one-size-fits-all” approach to medicine that relies on broad population averages. This traditional practice often fails because each person’s genetic makeup is slightly different from everyone else’s (He et al. ,2023). The advent of precision medicine is bringing us closer to more accurate, predictable, powerful, and personalized healthcare for the individual patient. Our growing understanding of genetics and genomics - and how they drive health, disease, and drug responses in each person

- enables doctors to provide better disease prevention, more accurate diagnoses, safer drug prescriptions, and more effective treatments for many diseases and conditions. Tailoring health care to each person's unique genetic makeup is the promising idea behind precision medicine, also known as individualized medicine, personalized medicine, or genomic medicine (Alowais et al, 2023).

Historically, the practice of medicine has been largely reactive. Even today, we typically must wait for diseases to appear and then try to treat them. Because we do not fully understand the genetic and environmental factors that cause serious diseases such as cancer, Alzheimer's, and diabetes (Salybekov et al.,2024), technology increasingly allows health care providers to shift the focus of medicine from reactive to preventive; predict disease susceptibility ,improve disease detection; anticipate disease progression; personalize disease prevention strategies; prescribe more effective medications; avoid prescribing medications with predictable side effects; reduce the time, cost, and failure rate of clinical drug trials (Alowais et al, 2023); and eliminate the inefficient trial and error that inflates health care costs and undermines patient care.

3.4 Artificial Intelligence in Medical Imaging

The application of AI is one of the most promising areas in health innovation, especially in medical imaging such as magnetic resonance imaging and computed tomography (Alowais et al, 2023), where it could contribute to predicting the diagnosis of cancerous lesions in oncology patients using texture analysis and other advanced methods (Gwillim et al. ,2024); predicting the treatment response to oncology-specific therapies, such as intra-arterial therapy for hepatocellular carcinoma; assessing the biological significance of borderline cases diagnosed in pathology through needle biopsy of mammography findings (Alowais et al, 2023); estimating functional parameters, such as fractional flow reserve from coronary angiography using deep learning; detecting perfusion and ischemia defects (Bignami et al, 2024), for example in the case of perfusion defects resulting from myocardial stress and induced ischemia; and segmentation and morphological modeling, such as brain tumor segmentation or, more generally, brain structure segmentation (Mijwil et al.,2023).

To illustrate the applications of AI in imaging, Table 1 summarizes key modalities and their AI-based contributions.

Table 1: AI Applications in Medical Imaging

Imaging Modality	AI Contribution	Example Application
MRI	Texture analysis, tumor segmentation	Brain tumor detection
CT	Automated lesion classification	COVID-19 pneumonia vs. CAP
X-ray	Abnormality detection	Chest radiograph screening
Ultrasound	Signal enhancement, image interpretation	Obstetric and cardiac care

4 Clinical Trial Efficiency and Accelerating Drug Development

AI plays a transformative role in both clinical trial management and drug development. By automating medical coding and optimizing patient recruitment, AI reduces trial inefficiencies by up to 70%, as demonstrated by IBM Watson's health applications. In drug discovery, AI algorithms accelerate molecular design, predict drug stability, and identify promising new compounds, thereby reducing costs and timelines. The integration of AI into trial and development pipelines ensures faster, more reliable outcomes, with the potential to reshape the future of pharmaceutical innovation (Adigweet al. 2024).

5 Informed Patient Care

Integrating medical AI into physician workflows can give providers valuable context as they make care decisions. A trained machine learning algorithm can help reduce research time by giving physicians valuable research results with evidence-based insights into treatments and procedures while the patient is still in the treatment room (Davenportet and Ravi, 2019). By streamlining healthcare workflows through incorporating AI as part of diagnostic services, healthcare organizations facilitate faster diagnoses and treatment decisions, improving patient outcomes (Alowais et al, 2023).

Sophisticated AI algorithms support radiologists, who read hundreds of medical images every day, helping them analyze images such as X-rays and MRIs faster and more accurately (Shaikh et al.,2024). This allows care teams to prioritize complex and urgent cases and detect cases that may require additional testing. It also alleviates staff burnout and supports staffing needs. In fact, time-consuming but necessary administrative tasks overburden staff and keep doctors away from the patient’s bedside. New AI tools can help alleviate burnout and free staff to focus on patients by automating manual and repetitive tasks such as entering data into electronic health records and submitting prior authorization applications to insurance companies (Davenportet and Ravi, 2019). In addition to supporting staff in their daily work, AI helps address staffing needs. Historically, hiring nurses has been a highly manual process that relies on phone calls, text messages, and spreadsheets. Today, we increasingly use AI analytics to streamline this process, including pairing team members who have previously collaborated because research shows that it positively impacts productivity (Inam et al. ,2024).

Furthermore, robotic process automation (RPA) performs organized digital tasks for administrative purposes, i.e. those involving information systems, as if they were a human user following a script or rules. Compared to other forms of AI, it is inexpensive, easy to program, and transparent in its actions. RPA does not only involve robots but also computer programs on servers. It relies on a combination of workflow, business rules, and the integration of the “presentation layer” with information systems to act like a semi-intelligent user of systems in healthcare (Davenportet and Ravi, 2019; Esquerda and Francesc ,2024).

6 Increasing physician-patient engagement

Many patients think of questions outside of regular working hours. AI can provide round-the-clock support through chatbots that can answer basic questions and provide patients with resources when the healthcare provider's office is closed. AI can also be used to triage questions and flag information for further review, potentially helping alert providers to health changes that require additional attention.

The following are the most important tools used to increase doctor-patient participation and increase effectiveness and partnership:

- **Intelligent virtual assistants (chatbots)**

Patients reach out to healthcare providers to seek medical help, find the right provider/doctor, schedule appointments, and address various other needs. However, healthcare providers may not have the staff to adequately assist customers with their queries. To ensure ongoing support, healthcare providers can implement AI-powered intelligent virtual assistants (chatbots) to automate responses to patients’ simple queries and requests (Morris et al.,2024).

- **Patient self-service portals**

Creating self-service patient portals is pivotal to addressing today’s patients who use digital technology and expect healthcare services to be readily available. Historical health records and lab reports, past appointment data, no-show/lateness records, discharge summaries, childhood immunization and vaccination histories (Malik et al.,2019), and healthcare provider notes (Alowais et al, 2023), enable patients to access relevant information and avail healthcare services from any connected device at any time. By incorporating advanced AI-powered features into these portals, healthcare providers can increase patient engagement, streamline processes, and enhance the overall patient experience. Modern self-service portals offer the user the following features:

- Appointment Alerts: Alerting the patient to the next upcoming appointment.
- Appointment Scheduling: Enabling patients to book, change, or cancel appointments anytime and anywhere.
- Doctor Recommendations: Recommending the most suitable and nearest doctors for patients to consult and automatically offering them a choice of time slots.
- Cost Estimation: Giving patients an estimate of the cost involved in consultations and other medical interventions.

- **Comprehensive view of the patient**

The healthcare industry is one of the most data-driven industries. Data in healthcare is generated through various channels such as patient registration, electronic medical record systems, physician consultation notes, patient feedback, and patient claims details (Bignami et al, 2024). Integrating patient data from multiple source systems is crucial for healthcare providers to get a holistic view of the patient.

- **Risk assessment for preventive care**

AI-powered solutions offer valuable insights to healthcare providers, especially in the early detection of diseases such as cancer, diabetes, and coronary artery disease (Alowais et al, 2023). By analyzing data from various sources, including X-rays and medical images, AI can help identify patterns associated with the onset of such diseases.

Furthermore, the integration of AI with smart devices, such as wearable smart bracelets, enables continuous monitoring of patients' heart rates (Bignami et al, 2024). This enables proactive health management and acts as a warning system, alerting doctors, caregivers, or patients about an impending heart attack or stroke and saving lives.

- **Automating medical coding and billing processes**

Spelling mistakes, abbreviations, and other ambiguities make medical coding time-consuming and resource intensive. This is where AI-assisted medical coding solutions can be a game-changing asset for healthcare entities, automating medical coding tasks to achieve the highest levels of accuracy and speed. This extraordinary improvement in speed translates into faster reimbursements and reduces financial stress for both providers and patients (Davenportet and Ravi, 2019). Fewer mistakes reduce the likelihood of billing disputes, fostering a relationship of transparency and trust between the provider and patients (Bignami et al, 2024). More importantly, improved accuracy and efficiency of medical coding improve health outcomes as physicians can rely on a more complete and reliable understanding of a patient's medical history, past treatments, and ongoing health issues to make informed decisions. This reduces the likelihood of missed treatments and allows for a more personalized approach to patient care (Alowais et al, 2023).

- **Automated Summarization of Physician Notes**

Another interesting use for AI in healthcare is in mental and behavioral health, where healthcare practices often face the challenge of manually summarizing large volumes of physician notes that flow into their EMR system (Alam et al, 2019). This challenge can be addressed with a transformative AI model that can be easily integrated into the EMR system. The AI model can adeptly assimilate and process large volumes of detailed physician-patient conversations from their question-and-answer sessions and automatically generate clear and comprehensive summaries of the conversations in real time (Shi et al.,2016). This improved efficiency and effectiveness of physician note summarization extends beyond administrative efficiency and becomes a critical step in enabling providers to quickly extract key information from voluminous notes and accelerate decision-making. Additionally, healthcare professionals can detect patterns, track progress, and proactively assess potential mental health concerns (Alowais et al, 2023), thereby improving the quality of patient care and experience.

- **Ethical Implications**

Finally, there are also a variety of ethical implications about the use of AI in health care. Health care decisions were made almost exclusively by humans in the past, and using intelligent machines to make or assist in those decisions raises issues of accountability, transparency, consent, and privacy (Grzybowski et al ,2024). Transparency is perhaps the most difficult issue to address with today's technologies. Many AI algorithms, particularly deep learning algorithms used to analyze images, are nearly impossible to interpret or explain. If a patient is told that an image has led to a cancer diagnosis, they will likely want to know why, and deep learning algorithms, even doctors who are generally familiar with their operation may not be able to provide an explanation (Davenportet and Ravi, 2019).

Justice in medical ethics emphasizes the equitable distribution of health care resources, treatments, and opportunities, addressing disparities and ensuring universal access. Integrity and confidentiality highlight the importance of honest and transparent communication while protecting patient privacy (Mennella et al.,2024).

Algorithmic bias has direct consequences in healthcare outcomes. For example, studies have shown that dermatology AI tools trained on predominantly lighter skin tones underperform when diagnosing conditions in darker-skinned patients, increasing the risk of misdiagnosis. Such cases highlight the urgency of incorporating diverse datasets and ethical oversight to ensure equitable healthcare delivery (Abbaoui et al. 2024).

- **Medical Data Integrity**

Since GenAI relies on large and extensive datasets often derived from electronic health records, there is an inherent risk of inadvertent disclosure/breach. PHI must be protected at all costs and cannot be loosely used or combined with publicly available LLMs. In fact, many healthcare organizations have now started using PHI-compatible versions of GPT and LLaMA for clinical integration of GenAI tools. Although patient data de-identification is practiced, challenges remain in ensuring that personally identifiable information is completely removed.

Finding a balance between the usefulness of the data for model training and maintaining patient privacy requires strong encryption methods, secure storage protocols, and adherence to strict regulatory frameworks such as the Health Insurance Portability and Accountability Act (HIPAA) (Deeb et al., 2024).

- **Key to the Future: Sustainable Innovation**

Technology is advancing rapidly and over the next 50 years, healthcare will change around the world, including the increasing use of artificial intelligence and robotics. Trends also show that climate change, hunger and disease may influence how the sector changes. Research shows that in the near term, in the next five to ten years, we are expected to see an increase in wellness technology in the industry, with the use of artificial intelligence and robotics. Telemedicine, which includes remote medical care, is also expected to increase, as is value-based healthcare, where hospitals are funded based on outcomes. In the medium term, within 10 to 30 years, data-driven personalization in healthcare is expected to increase. This type of medicine will use a patient's personal data to prevent, diagnose and treat diseases. Wearable devices are commonly used to improve the health of patients in cardiology, neurology and diabetes, and are expected to have a significant impact on the development of this type of medical care.

Today's world is changing rapidly and requires true continuous innovation to solve increasingly challenging issues. Of course, the important thing is to ensure that needs are met without compromising the ability of future generations to meet their needs. Therefore, it is imperative that governments, individuals and companies take some form of action to reduce their environmental impact. This is where medical cold chain manufacturers need to create sustainable refrigeration solutions that do not increase CO2 emissions but also allow researchers and medical professionals to continue their efforts. B Medical Systems, the global leader in vaccine cold chain and a major player in medical refrigeration and blood management solutions, is truly up for the challenge and can provide laboratories, hospitals and vaccination centers with sustainable cold chain solutions that can meet all their medical refrigeration needs on an ongoing basis. B Medical Systems aims to build a sustainable infrastructure for all pharmaceutical and medical institutions, and the team is dedicated to continuing to innovate to help create sustainable healthcare systems around the world.

The World Health Organization (WHO) defines an environmentally sustainable health system as one that "improves, maintains or restores health while minimizing adverse impacts on the environment and taking advantage of opportunities to restore and improve it for the benefit of the health and well-being of present and future generations." Discussions about sustainable health systems often revolve around emissions, although this is one of several different components. The medical cold chain is one contributor to emissions in the health system. Laboratories, hospitals and other research or medical institutions use cold chains every day in their operations, and these products can sometimes be energy intensive and produce significant carbon dioxide emissions. The medical cold chain, temperature sensitivity and emissions can be affected by the stability of many compounds at temperature, which therefore plays a critical role in molecular dynamics. The higher the temperature, the more likely it is that the heat energy will cause chemical structures to break down and form more stable ones. In the medical world, high temperatures can change the molecules in many drugs, potentially reducing their effectiveness. This problem can occur for samples such as blood and vaccines because they are heat-sensitive biological products. Important components within each can deteriorate if exposed to suboptimal temperatures, reducing their effectiveness. This would waste the research and clinical utility of these biological materials.

It is therefore understandable that it is of paramount importance to ensure that medicines, vaccines and biological samples are protected from temperature changes and stored and transported safely across their supply chain networks. The ideal solution is the medical cold chain: the name given to the network of freezers, refrigerators and medical transport solutions designed to keep biological materials at their ideal temperature throughout the distribution process.

These solutions are also among the most energy-intensive in the healthcare industry, even though they play a crucial role in maintaining the intended temperature required by many biological materials. Moreover, these units are at risk of causing harmful emissions and impacting the environment, since many of them use non-green refrigerators. The use of refrigerants based on chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) was common until a few decades ago and was present worldwide in refrigeration solutions. Eventually, these refrigerants came under scrutiny due to the severe damage they cause to the ozone layer and their greenhouse effect: they are now widely recognized for their ozone depletion potential (ODP) and global warming potential (GWP).

Therefore, these products began to be phased out naturally, and during the same period, a new type of refrigerant emerged, namely hydrofluorocarbon (HFC) refrigerants. These gases quickly found widespread applications because they had no significant effect on the ozone layer, but unfortunately, it quickly became clear that they were far from harmless as they were powerful greenhouse gases, causing a global warming effect up to 23,000 times greater than carbon dioxide (CO_2). The international community has launched many regulations on HFCs and the use of high-GWP refrigerants, with HFCs becoming the fastest growing source of greenhouse gas emissions worldwide, paving the way for the adoption of natural refrigerants. The most prominent of these regulations are the European Union's Greenhouse Gas Regulations and the SNAP program in the United States. Today, many cold chain products continue to harm the environment because their emissions are still present, although more manufacturers of these devices have begun to switch to green gas models and natural refrigerants.

- **The Sustainability Challenge for Hospitals**

Hospitals are at the heart of many clinical activities such as blood transfusions, surgeries, treatments, and more. This means that they often need to preserve many different types of biological materials, including vaccines, medicines, and different types of samples, which are often temperature sensitive. To achieve this, an extensive cold chain is required to meet the different temperature requirements of temperature-sensitive samples. As a result, hospitals have been at the forefront of discussions about the sustainability of high-quality, climate-friendly care. Moreover, with new requirements added to existing demands for quality healthcare services and disproportionate funding constraints, healthcare systems today remain under tremendous pressure from the pandemic. Hospitals are therefore thinking about how to ensure that operations are reliable, environmentally friendly, and cost-effective. In short, hospitals are focusing on how to create a healthier future for their communities while addressing climate concerns.

There is more than one advantage for healthcare organizations that have begun to understand the cold chain requirements of the healthcare system and ensure that the solutions used are reliable, energy efficient, and use green refrigerants. When designing sustainable infrastructure, one of the key aspects to consider is operational cost, and purchasing departments often opt for cheaper products to reduce initial purchasing costs. However, it is important to note that there can be a much higher total cost of ownership (TCO) during the life of the product, as these products may have high energy consumption and higher costs associated with heating, ventilation, and air conditioning. Mediocre products can also lead to frequent repairs or breakdowns, which can increase the cost of ownership. In extreme cases, mediocre quality can lead to premature replacement of the cold chain equipment and premature purchase of new equipment.

Several companies have used and continue to use their energy efficiency efforts with specially designed medical refrigeration and blood management solutions to operate on green gases, allowing them to bring more sustainable products to market. By using green refrigerants such as R600A, which have zero ozone depletion potential (ODP) and low global warming potential (GWP), the team has been able to significantly reduce harmful emissions. Refrigeration solutions are made more energy efficient through structural features such as insulated doors and sealed gaskets that reduce cold air loss and heat conduction. Medical pharmacy refrigerators, blood bank refrigerators, laboratory refrigerators, plasma storage freezers, laboratory freezers, low temperature freezers and transport boxes are offered to help hospitals in their sustainability efforts, as these products are designed with a keen focus on quality.

- **Ultra-low-temperature (ULT) freezers**

Ultra-low-temperature (ULT) freezers are typically used for long-term storage of samples at temperatures as low as -86°C, and are one of the most energy-intensive medical refrigeration products for sustainable healthcare systems. Genetic materials such as RNA and DNA, as well as cell and tissue samples, are just some of the biological materials stored inside these devices. Furthermore, the use of these products has been expanded by new developments in COVID-19 vaccine research, including the storage of temperature-sensitive mRNA vaccines, making them essential for global immunization campaigns. This is partly why hospitals are starting to deploy these products in large quantities, whereas just a few years ago these devices were only used in a laboratory setting. Ultra-low-temperature freezers can consume as much energy as an average household due to the extreme temperatures they need to reach. As a result of this high energy consumption, the potential for CO2 emissions is high. In some cases, an ultra-low-emission freezer and its associated HVAC system can produce up to 100 tons of CO2 over its lifetime.

Ultra-low freeze refrigerators are carefully designed with several features that increase energy efficiency. These include vacuum insulated panels and polyurethane foam, which together form a thick layer of insulation that reduces heat conduction through the cabinet walls. Silicone lip gaskets and foam provide an irresistible seal along with good thermal insulation and reduced frost build-up, especially when compared to traditional cavity-based gaskets. The ultra-low freeze refrigerator range also features two aluminium inner doors that ensure less cold air is drawn in and less heat is lost when the outer door is opened. These doors also have the function of sealing the freezer sections in a way that means that cold air does not escape the ultra-low freeze refrigerators completely when only one shelf is needed. This reduces the need for the appliance to operate overtime as it does not have to recreate the cold air that is normally lost when the door is opened. These units also use green refrigerants to further improve cooling efficiency. These refrigerants are known for their long-term availability and are also known for their long-term availability, ensuring that they are cost-effective.

- **B Medical Systems S.à r.l**

Are a global manufacturer and distributor of medical cold chain solutions. The company, headquartered in Heusingen, Luxembourg, was founded in 1979, when the World Health Organization approached Swedish manufacturing giant Electrolux to provide a solution for the safe storage and transportation of vaccines around the world. The company currently offers over 100 models across the three main business portfolios of medical refrigeration, blood management solutions and vaccine cold chain. B Medical Systems' main products include laboratory refrigerators, laboratory freezers, pharmacy refrigerators, ultra-low temperature freezers, plasma freezers, contact shock freezers, vaccine refrigerators (ice-lined refrigerators and solar direct-drive refrigerators) and transport boxes. All products feature 24/7 temperature monitoring capabilities, further ensuring that these products provide the highest level of safety and reliability.

EUHA directors and experts gathered for the Alliance's bi-annual General Assembly and a symposium titled "Rethinking European Health Systems: Creating a Sustainable Health Workforce for the Future" in London, all driven by the urgent need for reform. Almost every country in Europe is facing the challenge of caring for an ageing population, while struggling to cope with staff and resource shortages. At the same time, new patient care concepts are emerging every day, particularly in university hospital settings, and insights and findings from biomedical research are contributing to innovative treatment approaches.

So how can European health systems be future-proofed under these circumstances? How can staff be optimally attracted and trained? Could new preventative concepts for long-term health be the key to the best possible healthcare for all? Professor Hugh K. Cromer, CEO of Charité: "These urgent questions must be addressed. The COVID-19 pandemic has once again highlighted how much more needs to be done. We need to establish harmonized healthcare standards across Europe, strengthen collaboration in biomedical research, and develop a concept for training doctors and healthcare workers for the future. At the same time, pooling resources is essential, as this is the only way for us to develop innovative approaches capable of addressing these challenges."

This applies to the field of digital health and the creation of a common European health data space, which will allow health data across countries to be used for healthcare and research purposes. It is about strengthening systems and structures at European level and developing smart tools: "In our digital age, the healthcare sector must be able to process large amounts of clinical data systematically and thus also to benefit from them in order to support innovations in medical technology and patient-centred medicine."

- **AI in Healthcare and Climate Change**

Recent studies report that AI-assisted systems in medical imaging can reduce unnecessary scans by 15–20%, thereby lowering energy consumption and imaging waste. Moreover, one life-cycle assessment estimated that autonomous AI could cut healthcare-related greenhouse gas emissions by up to 80% when combined with renewable energy sources and efficient data center designs. These quantifiable benefits emphasize the dual role of AI in improving healthcare delivery and supporting climate goals.

AI can also enhance a doctor's diagnostic capabilities, thereby avoiding the need for repeat examinations. When combined with a smoother workflow, it can help enhance virtual care and reduce unnecessary patient travel, leading to lower greenhouse gas emissions.

- **The Energy Cost of AI in Healthcare**

Training and using AI models is energy intensive. Healthcare applications account for more than 4% of AI usage today, requiring large datasets, complex algorithms, and multiple model updates. One study reported that a single large AI model consumes the energy equivalent of five cars over its entire lifespan. AI in healthcare relies on data centers that use servers, cooling systems, and networking platforms, all of which must operate continuously in controlled environments, consuming a lot of energy and accounting for about 1% of global energy consumption. Healthcare also produces large amounts of electronic waste due to the constant need for hardware updates. This waste can poison the environment due to the use of materials such as lead, cadmium, and mercury.

The high demand for natural resources such as rare earth elements negatively impacts biodiversity by promoting habitat destruction. The transportation and logistics requirements associated with AI also intensify the indirect environmental impact of healthcare-related AI.

- **Mitigation measures**

Possible solutions may include increasing the energy efficiency of AI models through techniques such as quantization and pruning. Improving infrastructure design, revamping hardware and software concepts, and efficient power management using dynamic voltage and frequency scaling could also reduce the environmental costs of AI. Incorporating renewable energy could reduce AI-related energy consumption. In fact, AI-assisted nuclear fusion reactor design could lead to progress in harnessing this energy source for AI in healthcare. Such steps require a comprehensive life cycle assessment of environmental costs, enabling scientists to seize opportunities to reduce the carbon footprint from start to finish. One study reported that "autonomous AI could reduce healthcare greenhouse gas emissions by up to 80%."

- **Collaboration among stakeholders is key**

In conclusion, artificial intelligence represents a powerful enabler of innovation in medicine, but its deployment must be guided by ethical, social, and environmental considerations. To maximize its positive impact, the following recommendations are proposed:

- Adopt federated learning and privacy-preserving methods to protect sensitive health data.
- Ensure dataset diversity to minimize algorithmic bias and improve equity in healthcare outcomes.
- Invest in energy-efficient AI infrastructure and prioritize renewable-powered data centers.
- Establish transparent regulatory frameworks for clinical AI validation.
- Encourage interdisciplinary collaboration between clinicians, engineers, policymakers, and ethicists.

By integrating these steps, healthcare systems can leverage AI responsibly while contributing to sustainable development goals.

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