Deep Science Publishing
https://doi.org/10.70593/978-81-984306-1-8_4

Chapter 4

Artificial intelligence-driven patient monitoring: Real-time insights for proactive care

Kiran Kumar Maguluri

IT systems Architect, Cigna Plano, Texas, USA.
kirankumar.maguluri.hcare@gmail.com

Abstract:

AI-driven patient monitoring provides real-time insights into patient health, enabling proactive care. By analyzing continuous data from wearable devices and sensors, AI identifies early signs of deterioration, facilitating timely interventions and improving patient outcomes while reducing hospital readmissions and healthcare costs.

Keywords

AI, Early Detection, Patient Monitoring, Proactive Care, Real-Time Insights, Wearable Devices

4.1. Introduction

Today's healthcare system is under immense pressure to deal with a variety of health challenges, including population aging, rising levels of biological risk factors, and the prevalence of multi-morbid conditions. This new context and the recurrence of pandemics in the 21st century have also had a significant impact on clinical practices. Healthcare practitioners and managers are now dealing with the challenge of complex diagnostic and treatment pathways, as well as managing more sophisticated medical interventions to ensure the continual improvement of patient outcomes. However, this is proving to be far from straightforward, as the growing demand for healthcare services far outstrips the resources provided to cater to them. Thus, healthcare delivery has become increasingly reliant on professional expertise, which in turn has led to an unsustainable demand for existing hospital resources. People prefer not to step into a clinical environment through advanced healthcare.

AI focused on the healthcare sector is changing healthcare. The potential is immense, creating the opportunity to support timely, more efficient, proactive, and safer care (Nampalli, 2023). Delving into the predictive function of AI, this essay focuses on some of the current challenges of patient monitoring and how AI can be used to transform it. The essay is structured as follows: drawing upon the changing dynamics of the monitoring systems, the purpose of monitoring, and specific extreme monitoring events that are now a pressing public healthcare priority. The next section analyzes the current gaps and the need for monitoring solutions.

4.1.1. Background and Significance

Over the years, invasive and non-invasive systems have been popularly employed to assess patient health parameters. Considering the limitations associated with invasive procedures, the focus has shifted to newer and more advanced techniques for monitoring. The lack of real-time data and the need for manual intervention are the two major limitations of conventional monitoring methods. Therefore, there has been an exponential increase in the development of wireless and digital health monitoring devices. Even after creating digital interfaces, it has been reported that no appropriate guidelines were available to offer telemedicine and telemonitoring solutions. Digital health has surged of late, giving rise to the use of AI for interpreting the vast amount of data captured through these systems.

Digital health has largely benefited the healthcare sector, aiding in the decoding of patterns to alleviate the surge in chronic diseases. Identifying potential high-risk populations before disease occurrence is an important diagnostic feature that can prevent a wide range of diseases. The use of AI algorithms for data analysis is transformational in healthcare. The healthcare industry generates petabytes of data, and AI holds the potential to generate insights from big data and help reduce manual labor for data analysis. With healthcare management being at the forefront and producing large volumes of data, AI is indispensable. The goal of a clinician is disease prevention. Given the current worldwide burden and leading cause of death due to chronic diseases, better patient monitoring and management technologies are vital. Advanced sensors can enhance treatment outcomes.

Initiatives targeting better patient care have become global research priorities. Medical faculty and physicists have been researching new disease monitoring and management solutions. With the increased involvement of AI, healthcare transformation is sure to happen. Thus, the marriage of AI with healthcare is undoubtedly revolutionary (Syed, 2023). An integration of doctors with scientists and physicists can lead to better disease management. In retrospect, AI techniques coupled with medical interventions are of paramount importance.

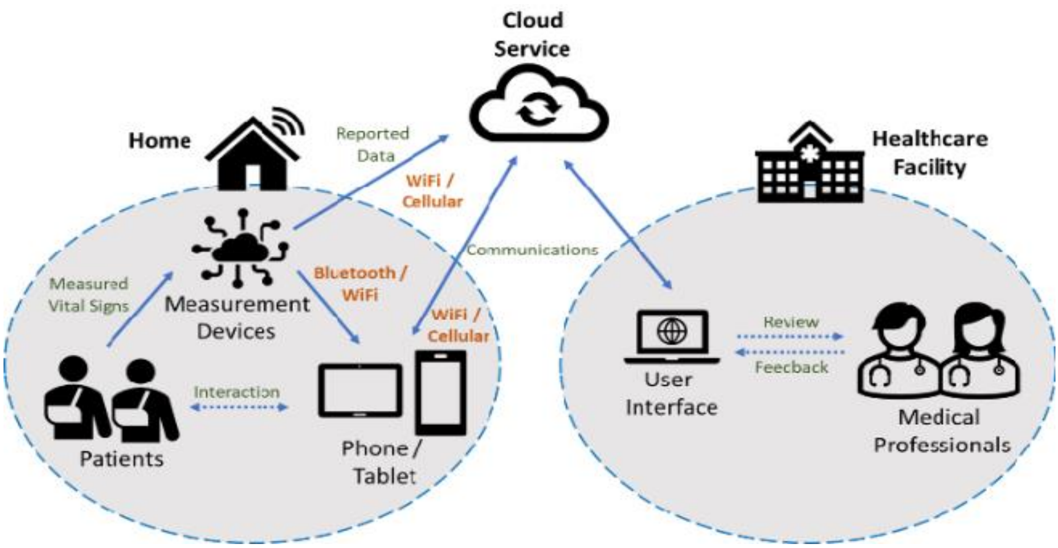

Fig 4 . 1 : AI-based Patient Monitoring System.

4.1.2. Research Aim and Objectives

The objective of this research project is to propose a patient monitoring framework powered by AI technologies. It will be employed to monitor patients in critical care environments with limited resource accessibility. The main objectives are to: (i) identify the potential AI technologies for real-time patient state assessment; (ii) analyze their capabilities in terms of patient management; and (iii) design a framework to represent the flow for monitoring the patients' statuses. This study is designed as the first step in answering the question of how AI could ease medical decisions by making them more effective and timely. This research aims to propose a way forward in this regard, reflecting on the research cycle as a structured approach to scrutinize the existing systems in terms of their mechanisms, practicality, and outcomes. The development of such a framework will promote a critical and well-informed debate in the healthcare community regarding the relevant technology. It may also persuade the community to take practical steps toward the use of such systems and to develop a real-time proactive care strategy. Thereby, it will also be a beneficial source for telemedicine companies and organizations for future expansions and strategies to cover all the potential scenarios. Discussions starting from this paper could provide valuable knowledge and ideas that will guide the suggested scope of the paper.

4.2. AI Technologies in Healthcare

Today, healthcare executives and providers use technologies powered by AI to accomplish a wide range of tasks, from identifying diseases through medical imagery to developing treatment plans and engaging patients in proactively managing their health and well-being. Some AI applications involve advanced machine learning techniques to complete statistically challenging tasks and predictions. Such tasks might involve image or voice recognition, the comprehension of natural language, and predictive modeling based on numerous variables to provide a readout of probabilities and their associated statistics. Accordingly, many AI tools support the application of data analytics to further inform clinical decisions and personalized patient treatment plans. Another type of AI tool is the application of human-like features and abilities that involve comprehension, logical reasoning, data gathering, and information efficiency. Essentially, AI systems perform functions at one or both ends of an existing infrastructure that is built to support human beings as they work, learn, achieve, function, and are entertained.

Most AI healthcare applications are integrated within a current structure or are integrated via open APIs and software development kits. This integration allows for better care decision-making, incentives for a patient to live healthier, application infrastructure commitments, and, in some cases, defense against liability assurances inherent in specific hospital-related policies. In practice, these technologies can be applied to patient monitoring, home monitoring, and telemedicine, allowing providers to systematically apply vital sign information toward early recognition of many health conditions. Consequently, monitoring applications are used to measure sustained heart rates, varying blood pressure, ECG, and others, which are constituents of the Current Monitored Alerts that are designed to lead to fine-grained health conditions in patients. This information about the nature and calculated distributions of these predefined events can track the accelerated pace of illness (Danda, 2024). In addition, AI can form impressions of normal implied distributions of CMAs in patients. AI can devise a correlation set of indicator

CMAs unfolding from this initiation and other standoffs of correlation data. Conducting a time-course monitoring of these indications, a strategic medicine treatment program can be prescribed in an outpatient or hospital setting. This is the niche occupied by AI-based patient monitoring for at-home vital sign devices.

Similarities among pioneering devices reside in predictive time-course assessment. To draw a similar choice, a characterization is needed beginning with the devices' AI memory docking for hearsay impression disposition. The anticipation certainty of the various systems is presented, followed by the general association between an AI agent-powered smart real-time monitoring system and a correlated infinitesimal asymptotic statistical heart shell for the ventricle of the heart. Accordingly, one model management of total anarchy will provide value-free health assessment in organopathy. Out-of-the-box healthcare assumes the presence of a template for hearing 'normal' that fits the hearsay 'correctness' pessimistic viewpoint. Finally, the bridging of device guides between home expectancy and medical professional service is delineated via a 12-lead ECG output as a complimentary exposition perspective. The adoption of this strategic approach will become implanted in hospital transition services and, possibly, global medical health servicing other than the U.S. or U.S. states with wireless ECG device licensed professionals.

Equation 1 : Signal Processing for Vital Signs:

$$s(t) = \sum_{i=1}^{n} a_i \sin(2\pi f_i t + \phi_i)$$

$s(t)$: Signal at time t (e.g., heart rate, EEG),

a_i: Amplitude of the i-th component,

f_i: Frequency of the i-th component,

ϕ_i: Phase of the i-th component,

n: Number of signal components.

4.2.1. Overview of AI in Healthcare

Artificial intelligence (AI) has the potential to transform healthcare. This is increasingly recognized by governments, health organizations, and industries worldwide, which have invested significantly in AI technology for healthcare in recent years. The development and implementation of AI in healthcare have been influenced by historical advancements in health, health informatics, machine learning, and natural language processing, culminating in recent work employing techniques such as deep learning and generative modeling. AI technology is being used across different settings and healthcare needs at an accelerating rate, including in hospitals or healthcare facilities, through applications that aid diagnosis, monitor patients, plan care, modulate treatment, and many other purposes. AI can be used either to automate tasks traditionally performed by healthcare professionals or to generate new clinical knowledge from large, structured, and unstructured datasets that can add value in guiding healthcare delivery, policy, or advancing research.

There are two main types of healthcare AI technology. The first, during the past 60 years, has been designed to imitate human thought processes and behavior, typically using if-then logic statements to make decisions based on input data. This technology is termed expert or rule-based systems and typically requires a good understanding of the problem to model. In the last 20 years, the second type, non-algorithmic or statistical AI, has become more widespread. This technology uses machine learning techniques to identify patterns, often in very large datasets, and to make predictions based on those patterns. This can produce results that are often more accurate than humans can produce because they can be trained on more data, taking advantage of digital technologies that can support the rapid analysis of complex data in real-time (Syed, 2023). An increasing amount of research supports the use of health AI technology for diagnosis, stratifying patient groups, delivering and planning care, suicide prevention, avoiding medication and prescribing errors, and more recently in the response to the pandemic. In addition to its direct benefits for health and healthcare, AI has also been used to improve operational efficiency and quality in healthcare settings by automating tasks such as scanning or transcription. Often these may have been originally designed for non-healthcare use but adapted for healthcare.

4.2.2. Applications of AI in Patient Monitoring

Incorporating AI within patient monitoring includes various applications. AI, in synergy with wearable technology, can form an essential service within a combination of home and community health settings, allowing real-time tracking of patient health alongside earlier discharge from hospitals. For in-hospital care, AI can be used to detect anomalies in patient outcomes or patient characteristics, extending to enhanced situational awareness for inter-operating computer-assisted monitoring. A clear application of AI in patient monitoring is to form part of a wider remote monitoring service, primarily targeted towards individuals with a long-term condition. With the rise of the connected patient and increasing ownership of smartphones and wearables, patients are better able to provide self-administered measurements that can determine a patient's health status with a higher level of accuracy and provide vital signs that can give strong early markers for potential complications. AI could also take part in the form of patient engagement activities, compliant reminders, and reconciliation of key information to patients.

Importantly, intervention based on the information extracted from AI outputs is key. The provision of insights is only half of the battle, as healthcare professionals should have validated pathways to react efficiently and effectively, to provide a meaningful impact on patient outcomes. Common challenges faced by healthcare professionals should also be acknowledged, including the large volume of data that requires interpretation and the subsequent actions taken. Furthermore, practitioner research has highlighted the need for these outcomes to be rapidly available and as real-time as possible to remain relevant to the clinical duties undertaken. Despite these difficulties, an emphasis on the research required to further merge the conceptual analysis of how AI could improve patient monitoring from the perspective of the patient and clinician is necessary. The adoption of AI within wider hospital care systems comes with a complex range of considerations, from how outputs can be interpreted to how interventions from healthcare professionals can be improved.

4.3. Real-Time Patient Monitoring Systems

Real-time patient monitoring systems are becoming increasingly important components of proactive healthcare. However, a clear and concise definition of such crucial systems is difficult to derive despite their importance. In general, real-time patient monitoring implies the continuous collection of one or more patient signals using hardware, the transmission of these signals to software, the identification of clinically relevant trends from these signals, and the distribution of any notifications based on these trends to the relevant clinicians. Some examples of these systems are closed arterial blood pressure monitoring, pulse oximetry, and capnography (Nampalli, 2022).

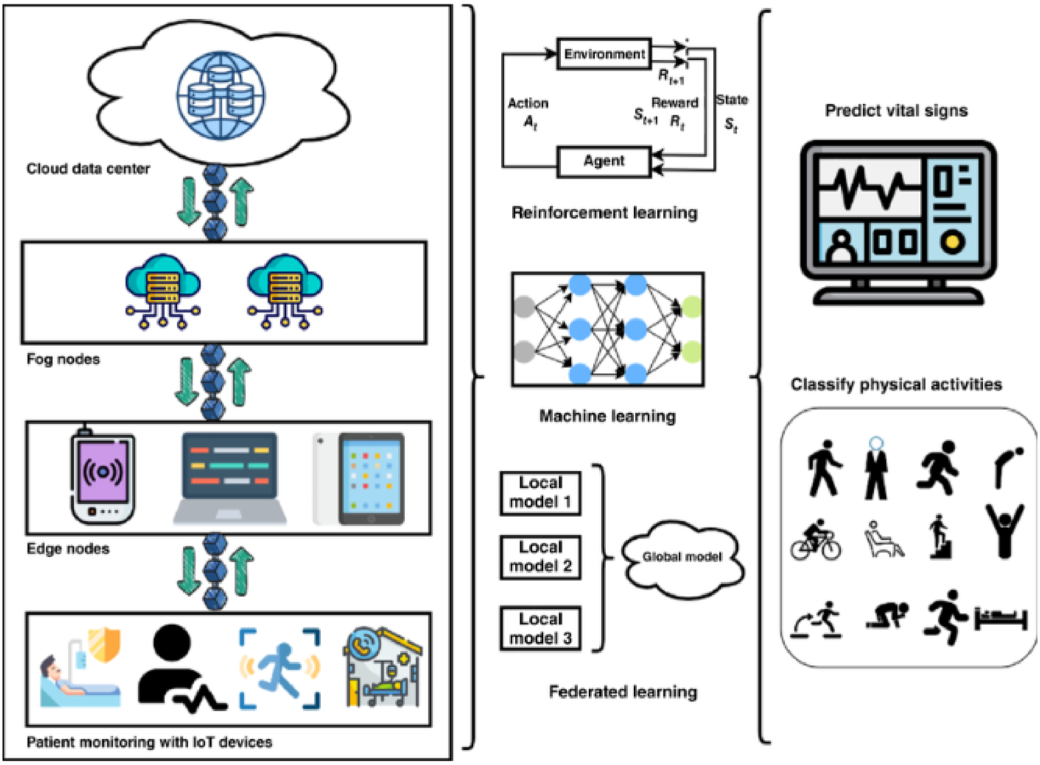

Fig 4 . 2 : Artificial intelligence-enabled remote patient monitoring.

It is not the data collection or the sensors themselves that define real-time systems, but rather the immediacy with which their results can be acted upon. Because of the continuous nature of real-time monitoring, there is ample reason to expect improvements in patient outcomes as a result of these systems. One real-time system will be more effective than another when it is capable of alerting a clinical professional before a patient's health deteriorates enough to require an alert from another system. Thus, two factors that will influence the success of any real-time patient monitoring system are how quickly it will be able to raise an alert from the time when a patient begins to deteriorate and how infrequently it will raise an alert when a patient is not deteriorating. The benefits of continuously monitoring a patient are clear when faced with a patient condition, such as an allergic reaction, sickness, or injury, that could occur at any time of the day or night. It is clear that if such a condition occurs at an odd hour, there might be a delay of several hours before a doctor determines that it is necessary to conduct a further assessment or administer treatment.

There will unfortunately be some difficulties as real-time systems primarily work to address the immediate needs of people. If such a system were to become available now, it might take considerable time, perhaps even until tomorrow, to be widely employed. There is an abundance of reasons to believe that such a medical application may have failed. Such a system may be proposed to have potential if only it would substitute for or improve the overall process of care. As a great example, one device is capable of measuring glucose levels unobtrusively using a glucose sensor and is sending out wireless signals over the radio, on which the blood pressure, heart rate, SpO2 saturation, and more are now being measured. If such a system could provide care directly to the patient, clinical improvements would be expected. Many more innovations and enhancements in technology and their vital application to clinical research remain to be seen (Kothapalli et al., 2022).

4.3.1. Definition and Components

Real-time patient monitoring systems are those that provide an interface to healthcare providers for periodically monitoring the vital signs and other physiological parameters of the patient. This interface generally consists of a computer screen or a handy mobile device. The system consists of three main components: the information sources in the form of various sensors, the computational device that processes this sensor data, and the user interface that presents this data in an easy-to-understand and operate format for the caregivers. The sensors in the system are generally non-invasive, but that is not a strict requirement. These can be as simple and cheap as industrial temperature sensors to high-end imaging equipment.

The computational devices in the system can vary from low-end microcontrollers to modern embedded computers or PCs. The user interface of the system is also not standard; it can be web-based or a PC-based terminal application that displays patient data in the form of a multi-parameter physiological monitor. The communication between these three systems is primarily through wired communication using serial and/or network ports. These systems can also have wireless layers where sensors can be attached to the patient non-invasively or invasively, and similarly, patient data can also be transferred wirelessly to a fixed or mobile monitoring device. These systems can also be programmed and interfaced with a Hospital Information Management System that takes care of storing and processing the data. The quality of the patient monitoring system is based on various factors such as speed of measurement, responsiveness, reliability, ease of use, safety, information dissemination, accuracy, automation, and cost.

4.3.2. Benefits and Challenges

Benefits: “By design, a real-time monitoring system can acquire and process data promptly and potentially be the tool for providing rapid responses to observed situations, allowing clinical decisions to be made faster, thus enhancing patient safety. The direct use of real-time patient monitoring could allow for the detection of early signs and prompt treatment of acute complications, which, depending on the complication, could prevent patient morbidity and/or mortality. Outcomes that can be improved by using real-time data obtained from patients are timeliness, access, actionability, and intervention. Another important feature of real-time patient monitoring is the isolation of potential issues caused by or related to the technology used. By creating context-aware personalized models, there is also potential for patient engagement and satisfaction improvement with such a real-time monitoring system. As connected health becomes mainstream, patients become more engaged in their care, especially care with the potential to improve their lives and conditions.

Challenges: “Numerous challenges need to be addressed before the implementation of real-time patient monitoring can be considered. These challenges include but are not limited to technical, clinical, and managerial issues. These include system-based factors, patient involvement in health, high quality of collected data, the ability to automate a system, as well as business and financial impacts for healthcare facilities and their administrators. Additionally, great attention should be paid to privacy and ethical issues associated with the use of data, data reuse, and sharing. The one major disadvantage of real-time monitoring is determining the threshold, sensitivity, and specificity for real-time alerts that do not trigger many false alarms and the higher percent of sensitivity and specificity for the associated clinical signs. The evolution of real-time medical devices and the increased expectations of patients and physicians can be a significant driving force for continuous innovation in this area. A system that provides too many false alarms would be ignored, and a system that ignores real events or presents them too late would represent a failure in meeting patient care goals—the reason for continuous advancement in the guidelines for monitoring systems (Subhash et al., 2022).”

4.4. Proactive Care and Early Intervention

Today, healthcare systems worldwide are gradually shifting from reactive models, where a health condition is prevented only when it escalates into a disease, towards proactive care that identifies it before it emerges. This shift demands a comprehensive approach that goes beyond simply monitoring critical key performance indicators. Proactive patient care frameworks empower patients by providing them with support designed to assist in preventing health deterioration. Among other techniques, the utilization of virtual assistants is proving relevant. They can be programmed to provide reminders, generate health-related information, and even, through the use of AI, guide the lifestyle of the patient. This class of applications comprises the natural environment for the implementation of AI-driven patient monitoring platforms. Early detection of any deviation in the patient's health status can prevent acute exacerbation, alleviate the need for hospital admission, and ultimately enhance the quality of life of the patient and their dependents. Within proactive care frameworks, real-time data processing made by AI technologies is essential in providing concerning alerts and predictions to healthcare professionals and the patients' appointed families and carers' smart devices. Anticipating potential clinical incidents through the throughput of real-time AI-based decision support tools provides a relevant strong proposition. The concept of proactive care and early diagnosis is not novel. The implementation of such a proposition has largely been hampered by the lack of interoperability among healthcare stakeholders and the costs associated with multiple independent solutions potentially providing interoperability and integration at the clinical and operational levels.

4.4.1. Importance of Proactive Care

In this age of scientific discovery and technological advancements, we have moved towards a preference for early diagnosis and early treatment as they increase the rate of successful patient outcomes manifold. In the current world, there exists a stark departure in attitude towards patients from the conventional reactive model of healthcare, such that efforts are increasingly focused on treatment to wellness and from illness to prevention, all to promote proactive care. This transition has proven effective, especially in the treatment of chronic conditions for which symptoms are typically slow to manifest but pose serious long-term complications. Proactive care engages patients in actively managing their health. As a result, healthcare providers can focus on prevention and early detection of disease, which benefits not only the patients but also the providers and healthcare organizations, as well as payers, by optimizing available resources and reducing healthcare costs. This approach also aids in reducing the healthcare burden by deploying logical algorithms that authenticate patients with minor issues to seek self-care solutions rather than reaching out to physicians for every issue (Sondinti et al., 2023).

Fig 4 . 3 :Revolutionizing Patient Care with AI-Driven Diagnostics

Similarly, a patient is more likely to pull their life together if they are convinced that their doctor understands them and wants to create a care plan with them to move forward. At the root level of the discussions of how collaboration will look, the top discussion revolves around the fact that there is an increasing interest in acknowledging that physicians or the care team are not responsible for medical treatment. It is the patient who has to do more. The role of the physicians rests upon identifying the probable areas to assist the patient in understanding the necessary changes, offering them available solutions, and then letting them move forward on their journey toward health. This transition to proactive care is further augmented by advancements in technology driving early diagnosis and thereby prognosis. The latest innovations enable the design and deployment of learning strategies that are logical, clinically sound, free of bias, adaptable, and flexible. Once the personalized protocols are set up, they become adaptive learning systems, thereby replacing the need for manual interventions during treatment planning. It contributes to the successful deployment of the concept of proactive care and opens new vistas in precision medicine for improved patient management.

4.4.2. AI-Driven Early Intervention Strategies

AI has an enormous scope for driving innovative strategies in early intervention at the individual patient level. Using predictive analytics to identify patients at risk of deterioration is a critical tool for designing a proactive care paradigm that may contribute to earlier intervention and greater impact. As such, this may be incorporated into the concept of "predict, stratify, support, and learn." AI methods are integral to the development of robust predictions, risk stratification tools, and the use of data to support ongoing adaptation and retraining.

AI models can be used to derive an optimal cutoff to provide the highest area under the receiver operating characteristics tradeoff between positive and negative predictive values. AI-based alerts to changes in physiological parameters or outcomes can be associated with earlier changes in treatment or intervention decisions as a result of the powerful data-driven insights these AI approaches provide. In the ambulatory environment, Pediatric Intensive Care Unit clinicians were more likely to consider additional workup in cases where an acuity score was driven by AI-driven data as compared to events where the acuity score was driven by other data.

Finally, a case study demonstrates reinforcement learning approaches to personalize an individualized sepsis management policy in real-time. This strategy improves care in silico, exploiting a Bayesian optimality boundary to guide real patients on an aggressive trajectory before returning to the standard of care. Their model parameters were trained on simulated patient encounters drawn from electronic health records and tested against more in silico cases; the approach led to real patients achieving better outcomes compared with the current clinical environments. It is currently likely that some interventions are evident early enough for clinical intervention to be meaningful. Equipping clinicians with broader physiological monitoring of real-time physiological data may help drive earlier decision-making to help facilitate the right care for the right patient as well as help prevent acute clinical deterioration. AI-driven strategies have the potential to help identify patients with an enhanced vulnerability or those demonstrating inverse care trajectories, providing an opportunity for adaptation. The intensity and need for co-development of technology and relationships with healthcare professionals have led to slower translation in some settings (Vankayalapati et al., 2023).

These AI-driven strategies will need to be trained but will also need to have adaptive capabilities. This is particularly true of adaptive physiological monitoring that shifts in response to interventions or treatment changes. Such learning will need to be carefully managed within clinical pathways to ensure alterations and escalation in care can proceed as necessary. Investment in AI technologies that enable the identification of at-risk patients early can help contribute to transformational early intervention strategies, including the use of predictive analytics to develop specific care pathways for high- and low-risk groups based on last-known health.

Equation 2 : Anomaly Detection for Alerts:

$$A(x) = \|x - \mu\|^2 / \sigma^2$$

$A(x)$: Anomaly score,

x: Current measurement vector,

μ: Mean of normal data,

σ: Standard deviation of normal data.

4.5. Case Studies and Success Stories

Nonetheless, many examples exist of successful case studies demonstrating that AI-driven surveillance can lead to patient engagement and satisfaction, drive clinical efficiencies, and push the healthcare industry as a whole toward the direction of value-based care. Just some of the written success stories before us include: the estimated number of readmissions prevented through remote monitoring over five years; and close to $1.3 million in savings over eight years spent by long-term care organizations by releasing high-risk patients from skilled nursing facilities to their homes where, under the watchful care of family and medical personnel, they have since thrived; and the collaboration between scientists, engineers, and doctors at a hospital, which represents one of the most important and successful documented tests of remote monitoring using home health medical devices and, as part of the study, an AI-driven early warning system for disease management.

The launch and early adoption of an AI-based pre-hospital emergency medical care system for victims in a region. Each case presents a different approach, mindset, and results that cater to their audiences. What they all have in common is the power of technology and innovation changing the healthcare playing field. In doing so, they offer us valuable insights into the future. They also prove the advantages we'll gain by collecting such examples of success and providing them for everyone to see and hopefully replicate. By clinching admission, acceptance, and interest in clinical and industry conferences, it's proof not only that there's value to what we're doing, but also that there is a path to leading the charge in terms of quantifying technology's success in a clinical care setting.

4.5.1. Real-World Applications of AI in Patient Monitoring

5.1.1. Hemodynamic Monitoring in the ICU Following successful preclinical validation, the AI was tested in a retrospective manner using de-identified waveform data obtained from two ICU centers in the United States. The developed AI model was capable of accurately and efficiently assessing multiple physiologic signals from single-center ICU patients, as well as patients in an external data set. Across the AI assessments, 70–90% of included subjects presented hemodynamic instability during their ICU stay. The AI-generated hemodynamic assessments provided additional information by assessing the flow distribution through various hemodynamic profiles. In patients moving from euvolemic towards hypovolemic status, the AI predicted a decrease in the volume of blood circulating in the body before standard medical interventions would have suggested any deterioration. The AI system is now well integrated into the digital ordering and management portal electronic infrastructure and is now being validated in a prospective trial. A combinatorial approach was used to prospectively recruit ICU patients meeting specific hemodynamic inclusion criteria into a recently completed study. AI-guided patient monitoring and care significantly reduced the time interval between an intervention for a physiological problem and improved that problem by 39% compared to a control group. Furthermore, there was a trend towards fewer patients developing sepsis-related organ dysfunction in the AI-guided clinical pathway compared to the control group. Overall, there was a 4-fold increase in patients' early detection of deterioration from clinical criteria alone in the sub-study.

4.6. Ethical and Legal Considerations

AI-driven patient monitoring solutions must be developed and used responsibly and with the patient's best interest in mind. There are several ethical and legal considerations involved in the development and deployment of AI systems, which need to be addressed by all stakeholders involved. Patient data privacy should be protected, and the individual should have control of the data being shared. The solution must comply not only with the regulations for data privacy and security but also with the medical device regulations and general healthcare regulations as it directly deals with patient data. These regulations cover informed consent, data usage, and sharing.

When it comes to AI, it is especially hard to have informed consent because it is unclear how the data will be used and shared. Hence, solutions need to ensure data subject rights and sharing of information where the AI solution is used; informing the patient that their data will be used for algorithm training and that the outcomes may potentially be published in a non-identifiable manner. The bias and fairness of the algorithms need to be considered. Bias can have severe consequences in healthcare. It is the responsibility of the healthcare professional or the clinical governance team to monitor and investigate AI performance and its impact on clinical outcomes. If AI tools are recommended for certain actions, informing the responsible healthcare professional how this decision was reached is essential. All stakeholders can have a role in reminding health professionals to perform appropriate investigations if they notice AI or digital health behaviors that may have an impact on patient care. The developers will need to commit to ethical guidelines and practices in their development and deployment methods. There needs to be both transparency in AI and algorithm explainability. AI ethics guidelines that have been published need to be adhered to. Therefore, there is a need for ethical guidelines for AI in healthcare.

4.6.1. Privacy and Data Security

AI-driven patient monitoring depends on collecting and analyzing individual patient information. Privacy and security are, therefore, paramount in this environment. Research and analysis results of data from these types of systems must be cautiously evaluated to ensure no personal identities are exposed. Regulations require removing specified direct identifiers and all other unique identifying characteristics of the subject to be held confidential before a database can be shared for research purposes. These regulations resulted from the general mindset in research institutions that the disclosure of a primary key could lead to the release of the entire database.

Sharing these types of data for research and statistical purposes is necessary for the advancement of healthcare. As patients move through various healthcare ecosystems, and commercial artificial intelligence and machine learning models are applied for various use cases, data integrity is at risk. Today, EHR systems do not track images taken from DICOM viewers that can be imported to support clinical care. Similarly, they do not track information being shared for second opinions. To address this gap, materials, and methods are being developed to track this process by providing visual cues to the user. Thoughts on this approach are provided. Maintaining the integrity of healthcare data is essential for the reliable use of AI and algorithms. Part of maintaining data quality facilitates many applications, studies, and reports both within the ECCH and to external stakeholders, including clinicians, investigators, patients, and government officials. It also provides standard benchmarks required for the validation of scientific research. A powerful AI model that has been trained on data resulting from inappropriate data sharing may obtain results that are less than intuitive, or worse, are dangerous to the patient. There can be no doubt that as more devices begin monitoring data and transmitting it to EHR systems, the need for giving special care to ensure data integrity will be key to the success of AI technologies. It is also debatable whether patient trust will be forthcoming for AI systems if there is an understanding that algorithms for the software being used were trained on data from patients who did not provide consent for their use for that purpose. Turning to the concept of privacy associated with the use of AI, discussions have been made about data and analytics being accessed through the principle of differential privacy in democracies and Orwellian states.

Privacy and data security must play a paramount role in healthcare. Even in a non-technical sense, as personal data is shared more widely with organizations, breaches, and hacking attacks are no longer a question of "if" they will occur, but rather "when" they will occur. Purposefully, the section on policy and legal implications of data sharing has been included in this report before data analytic techniques for a further discussion of AI and big data can be used to address their application in patient-level new approaches to data integrity and security can be discussed. This report seeks to present the need for a multi-stakeholder approach to addressing integrity and security within the big data AI-driven ecosystem.

4.6.2. Bias and Fairness in AI Algorithms

Critical Challenges There are well-documented challenges around bias and fairness as we develop and implement AI algorithms for patient monitoring. Subtle biases may be present in healthcare algorithms that put certain types of patients at risk for unequal care. Bias can also compound decision-making in clinical settings and potentially lead to systematic disparities. These disparities are particularly important in the downstream application of an AI-driven patient monitoring system. Fairness in AI is a critical determinant of access to care, resource allocation, and protocol setting. Strategies for Mitigating Algorithmic Bias Many strategies can be deployed during the design of a predictive algorithm to mitigate bias, including using a cohort of sufficient size and diversity in your development dataset that is representative of the patient population to which your algorithm will be applied, as well as collaborations with other groups or integrated data resources in the field of patient monitoring to increase diversity. There is a strong need to engage with stakeholders such as patients and providers to develop appropriate evaluation frameworks and methods to determine trade-offs with the health and accuracy of any precision medicine approach, as well as publicly and transparently report the steps taken to mitigate bias with the use of detailed evaluation metrics. Case Study Multiple investigations suggest that most published literature discussing the use of AI in critique shows that this tool does not affect a similar but larger group of minority patients. Such research suggests even small biases in the application of AI for patient monitoring may prove costly at scale and in a highly stressed system. Taken in aggregate, these case studies highlight the following: Bias in healthcare algorithms is prevalent when they are implemented within the health system; biases in healthcare algorithms have significant impacts on patients, even if they are unintentional initially; there are few systematized ways to prove that bias does not exist; improving fairness in healthcare algorithms likely needs to happen at multiple levels with the collaboration of numerous stakeholders (Maguluri et al., 2022).

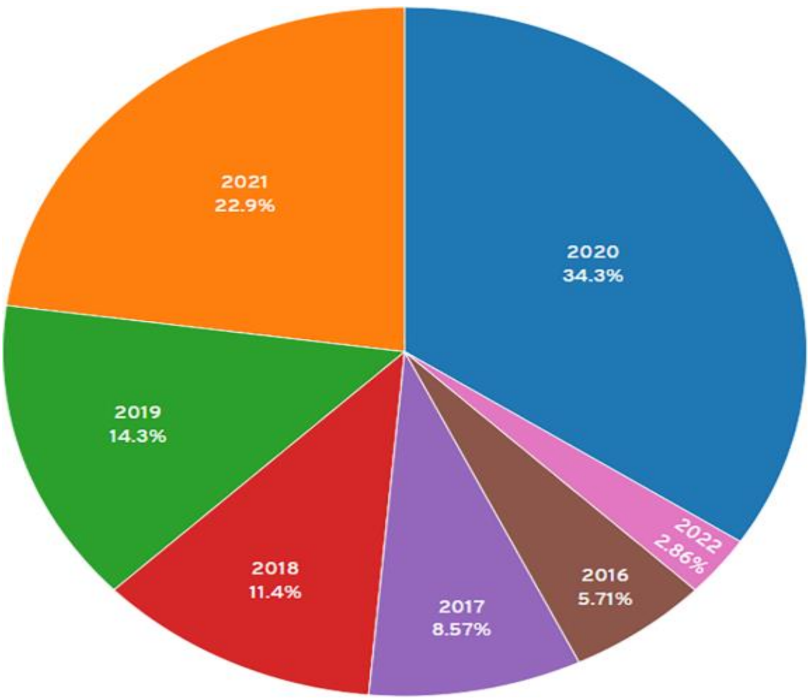

Fig 4 . 4 : Remote patient monitoring using artificial intelligence.

4.7. Future Directions and Conclusion

The next steps in AI-driven patient monitoring may include telemedicine integration to leverage both reactive and proactive care tools more effectively, and advances in predictive analytics as the technologies are further refined. Insights emphasize the growing demand for chronic disease monitoring among patients. Chronic ailments unanticipated by affected populations also indicate the need for a range of monitoring systems, such as ear infection detection among children. The survey and technological audit both further illustrated the different needs of patients for ongoing monitoring of both chronic and acute ailments. Current strategies are typically predicated on the patient reporting back to a physician once self-identified signs are detected, leading to diagnostics and care intended to manage symptoms after they have had time to develop, often unreliably in terms of both accurate diagnosis and effectively responding to care. Participants suggested that AI can help in situations where biomarkers or other diagnostics are unavailable, impractical, or cost-prohibitive. AI could therefore potentially add value to the monitoring systems being developed and implemented for both chronic and acute ailments.

The following outlines general conclusions considered critical for further study of AI and proactive patient care. Current patient monitoring systems are typically employed for reactive care strategies. Most involve patients monitoring themselves and then waiting until their symptoms are great enough to trigger them to report their distress to a healthcare professional. AI is anticipated to be an invaluable contribution to proactive care, as a bridge for providing valuable, predictive early warning. To effectively apply AI and meet the needs of future users, interdisciplinary strategies that embrace a wide range of relevant expertise will be critical. This work is intended to build AI advantage and economic opportunity while responding to the healthcare challenges faced by all nations. With so many patients at risk now due to examined diseases and increasingly wearable technology, there are substantial and immediate impacts that may come from the work that should be delivered to Canadians and others in timely and affordable ways. With public health interests at the forefront, we are sharing what we have learned rapidly and widely using a range of strategies. Further study options and international partnerships are under consideration to move towards real-world case development for AI-assisted proactive patient care.

4.7.1. Emerging Trends in AI-Driven Patient Monitoring

Real-time monitoring of patient data is an important aspect of proactive patient care. The information gleaned from patient monitoring has a direct impact on patient care and outcomes, and as such, many health systems are investing in digital tools that will allow greater usage of these insights. AI is increasingly gaining accuracy in a complex task such as patient monitoring, giving unprecedented opportunities for rural healthcare providers to reduce their work burden and costs. The advent of wearables and the increasing volume of patient-generated health data are bringing new opportunities to engage with patients and increase the accuracy of the data used for patient monitoring. The incorporation of multiple new non-intrusive sensors and wearables for patient monitoring has enabled the tracking of patient activity state and detection of patients' abnormalities by correlating it with other parameters.

With the help of AI-based backend analysis, data security and accurate transmission can be ensured with minimum human interference. A revolution in remote healthcare systems is coming where wearable sensors and the integration of a wealth of technology could make it possible to diagnose and monitor the patient in real-time. The measurements and derived data from the recent development in advanced patient monitoring systems can help doctors make data-driven decisions for a better cure of morbidity. However, technology adoption within the care domain is a complex process, involving many stakeholders, not only the intended users but also the providers, decision-makers, and other stakeholders. Although patients can receive improved care with these advancements, healthcare providers face many challenges associated with adopting these solutions at every point in the healthcare supply chain. Because of the potential value of technologies developed in patient monitoring for healthcare delivery, user-centered design techniques must be applied in the early development concepts of systems, sensors, and wearables. This could lead to the next era of patient monitoring system development capable of facing constraints as well as fit-for-task in delivering future healthcare demand strategies.

4.7.2. Summary of Key Findings

- AI technologies that are enabling proactive care and real-time insights have the potential to greatly improve patient care and health outcomes. To integrate AI-driven patient monitoring into routine care, necessary evidence has to be generated. To do so, we partnered with technology developers and front-line clinicians to answer the research question: What is the current evidence base regarding continuous monitoring systems to identify patients at risk of developing acute illness? - Common conclusions are that real-time monitoring systems show promise, that continuous integration as a part of early intervention strategies is necessary to realize benefits, and that care providers, patients, and families should be engaged in the technological framework's design, evaluation, and deployment. Developers and healthcare providers must work together to further refine real-time monitoring systems and the interventions that are integrated within them. While we go to press, further evidence about these systems will continue to emerge, and thus there is still much more to be discovered.

We found that while there is excitement around the basic possibilities of AI-driven patient monitoring and the early intervention strategies facilitated by such systems, there is currently limited field experience with them. We also uncovered the following ethical considerations that current research does not provide an answer to: What patient information is appropriate to capture, process, and use to proactively intervene in patient care? There is a broad array of patient health information; what specific signals indicate interventions and what does not are not well defined. Further, measuring and spotting such signals may also reveal underlying bias in the healthcare system. What will we do with this information? What should be done to intervene early in patient care? Information privacy is an important aspect to consider, as well as patient consent to continuous monitoring. Will this information be accurate? As well as the impacts of this, will it provide us with genuinely valuable insights? Furthermore, there should be deep consideration of feedback loops and labeling and the system's potential when there may be no disease present or when a patient does not know they have a pre-disease condition. AI technologies, in particular, may also be inclined to incorporate biases when developed, trained, and implemented.

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