Research Article

Smart Emergency Department: A Technology-Driven Emergency care Model for the Future

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Abstract

The current model of emergency care is being challenged with increasing demand as well as the current COVID-19 pandemic. This review presents a different approach to emergency care that is technology-driven to meet future demands. The focus is on adoption of new and emerging technologies, including artificial intelligence, the internet of medical things, cloud technologies; mobile apps, patient wearables; and decentralized patient records using block-chain technologies to provide care in the pre-hospital setting, emergency department as well as during subsequent follow-up. Many technologies discussed herein have shown great potential in other industries and are part of industry 4.0 protocols. Appropriate use of these tools will transform emergency medicine into one of the most technology-savvy, future-ready medical specialty.

Keywords: Emergency department; Smart technology; Artificial intelligence; Industry 4.0; Telemedicine; Personal wearables; Cloud technologies.

Introduction

Despite emergency medicine being a relatively young specialty compared with other branches of medicine, the global recognition and demand has grown significantly due to the need to provide timely emergency care to the people. [1] This increased demand and provision of effective emergency care has been clearly demonstrated during the Coronavirus disease 2019 (COVID-19) pandemic when most Emergency Departments (ED) were overwhelmed. [2] Our traditional care models were challenged with new requirements during this period, stressing every aspect of the patient's journey from the pre-hospital setting to the ED. These challenges can become the new norm unless we are able to re-design and future-proof our emergency care delivery model. At the beginning of the 21st century, manufacturing, banking and automotive industries were challenged by a lack of productivity, connectivity and reliance on human factors, which led to slower growth. [3] These challenges can also be related to the ones in healthcare sector, especially in the ED, if we consider the patient's journey as a process. However, most of these industries managed to adapt their process to meet these challenges with the help of new and emerging technologies, now collectively termed "Industry 4.0". [4] Basic technological principles being the same across most industries, Industry 4.0 has transformed various sectors to use technology-driven processes that provide a better fit for the future. This review focuses on the use of several of these technologies to re-create the patient's journey through the ED as a "Smart ED" experience.

Discussions

A. Current challenges in the emergency department

Based on the patient's care journey, we can categorize the challenges into two categories, the first one during the provision of emergency care within the ED, and the second comprising of the challenges affecting the patient outside the ED, both before their arrival to hospital and after leaving hospital.

Within the ED itself, the main challenge by far is overcrowding. [5] This problem is very complex and multi-factorial, encompassing challenges related to input, throughput and output. Throughput can again be caused by many reasons, but a lack of efficiency in certain processes contribute significantly to the issues of throughput. Other industries previously faced similar problems, one example being the banking sector, wherein the physical banking location was overcrowded with customers seeking financial services. They managed to solve this problem by leveraging on the use of smart technology-driven solutions, and availing their service provision online and in the cloud space. Furthermore, emerging technologies such as block-chain and cryptocurrencies are threatening to further eliminate physical banking. [6] Some of these principles can be applied to ED, as discussed in the next section.

Another major challenge within the ED is the patient's length of stay, which can be attributed to process inefficiencies. The main aim for care provided at an ED visit is to determine a diagnosis or risk stratify a condition so that immediate treatment can be initiated. This type of data-heavy processing can be aided by Artificial Intelligence (AI), which plays a key role in smart technology utilization. In addition, associated processes related to billing and drug dispensing also cause "bottleneck" delays in the throughput time of the patient's overall ED journey. A lack of connectivity among processes is partly to blame. Some principles of the smart production line and IoT can be applied to patient journey through the ED to reduce the length of stay.

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The second challenge includes the pre-hospital lack of patient information or triage before their arrival at the ED, followed by a lack of their monitoring after leaving the hospital. For example, a lack of emergency medical transport systems' ability to connect to the ED to provide detailed pre-arrival information as well as lack of monitored follow-up after discharge may lead to unnecessary hospital admissions and repeat admissions. [7] Other industries faced similar problems with regard to quality assurance in a production line. For example, the microchip manufacturing industry has automated many pre- and post-production quality checks using AI based predefined criteria. Likewise, EDs can also use smart technologies such as mobile apps and wearable devices together with cloud monitoring to solve these issues. In addition, algorithm-based protocols driven with the help of AI can reduce the stress on emergency transport services.

B. What Are smart technologies and what makes them special?

The term "smart" derives from the acronym SMART, meaning "Self-Monitoring, Analysis and Reporting Technology." The term has become widely known as "smart" also because of the notion of allowing previously inanimate objects—from phones to cars —to talk back to us and even guide our behavio. [8]

In general, "smart technology" is an umbrella term used to describe interconnected devices or processes that perform relatively normal functions with a greater degree of autonomy without human input than their non-smart equivalents. Some of these terms and definitions are interconnected and use or describe industry 4.0 standards. [6] These technologies, which include physical and logical applications in all formats, are capable of automatically adapting and modifying behavior to fit the environment, gathering input with sensors, providing data for analysis and inference, and drawing conclusions from rules. A smart technology is also capable of learning, so that it can use its own data analysis and experience to improve performance.

Key elements that differentiate smart technologies in healthcare from current technologies are software apps and sensors; the interconnectivity between things and humans—termed the Internet of Medical Things (IoMT) and Internet of Humans (IoH); the use of cloud space, which reduces the dependance of physical space; and an ability to make decisions with the use of AI. [9]

C. Technology-driven smart emergency care

In order to serve patients better, it is critical to understand their perspective of needs and demands. With this analysis, emergency physicians and EDs can appreciate what technologies to focus on for early adoption. We will discuss several smart technologies that are suitable as part of patient's emergency care journey.

(i) Pre-Hospital emergency care

The present-day millennial's "mobile-first" approach to everything in life changes how they react to an emergency situation. [10] Most millennials refer to online resources or mobile applications as their first reaction. Indeed, a large growth of medical-related apps caters directly to this segment of the population. Specifically, in emergency situations the most valuable apps are those that use IoMT technology to connect to wearables with senses and use cloud data storage and data analysis to predict results. A lot of development has occurred in wearable technology; for example, a watch can measure cuffless blood pressure, and even certain biochemical markers such as serum sugar levels or lactate can be measured noninvasively. [11] This technology enables patient-owned wearables to monitor all the important physical parameters and vital signs, including heart rate, respiratory rate, oxygen saturation, blood pressure, heart rhythm assessment through Electro Cardio Graphy (ECG), and biochemical parameters, and to store these data in the cloud. Furthermore, it can make autonomous decisions regarding when to alert the user and healthcare providers of a potential emergency situation. The most well-known example is the Apple Watch for recognition of abnormal heart rhythms. [12] This wearable device manages to capture and analyze abnormal rhythm situations and notify the user and even their physician if the user sets instructions in the app. This closed loop action exhibits all the smart features.

Today, a big drive exists to create patient-owned, cloud-based records of health data, and some entities are using block-chain technologies to store and share data securely. This approach is a significant difference from the current practice of hospital-owned and stored Electronic Health Records (EHRs). When a patient-owned secure EHR is fully mature, it can offer a lot of benefits to both the patient and the ED. These patient records can enable better data analysis from wearables and prediction of outcomes. For example, if a smart app knows that user is a patient with ischemic heart disease, it can lower the risk threshold for abnormal rhythms and more quickly initiate a response. Other benefits of patient-owned EHRs are that a patient can decide with whom to share these records and how much of the information can flow to the other party, which gives the patient ultimate autonomy.

Moreover, apps for symptom analysis are gaining popularity, and their credibility increases daily owing to advanced algorithms and the ability to analyze big data [13], which is especially popular among young populations. With the current advances in the field of Natural Language Processing (NLP), we predict that these apps may become equal to general practitioner for the assessment of initial symptoms.

Combing the above-mentioned technologies, we would be able to perform all the steps done at ED triage, including symptom analysis, assessment of vital signs, and simple point-of-care tests, such as ECG and biochemical tests—all at the fingertips of the patient. By doing so, we can effectively triage patients before we dispatch our physical resources such as ambulances and/or other Emergency Medical Services (EMS). Another big advantage of these technologies is that they can perform repeated assessments, thereby providing continuous triage at multiple time points.

Simultaneously, these smart technologies can also improve the patient care provided by EMS en-route. [14] The IoMT technologies can facilitate sharing patient's vital information between EMS and the destination healthcare facility. Also, IoMT technologies enable geo-spatial deployment of EMS based on the trend of utilization, and can locate a destination hospital with

suitable facilities and even can check the availability and waiting times. For example, if a patient with acute myocardial infarction needs urgent coronary intervention, based on patients' wearable electrocardiography readings, the EMS data operation center should be able to locate a hospital with coronary intervention facilities and an available patient bed. [15]

(ii) Emergency department care and observation

Providing emergency care for seriously ill patients is challenging and requires data processing from multiple sources for rapid decision-making. In contrast to many emergency physicians who believe that technology is of little help in this patient population, current smart technologies have shown great benefits for assisting physicians to better manage these patients. [16]

One of the important technologies emerging from this field is the Natural Language Processing (NLP)-assisted diagnostic and risk assessment tool in the patient's EMR. When the emergency physician documents the patient's details in the EMR, the system can provide real-time recognition and suggest a diagnosis and risk probabilities for certain conditions. These automated processes can truly be useful in stressful situations to offload the mental capacity of the care providers. For example, sepsis is one of the leading causes of morbidity and mortality in EDs and hospitals, for which early detection and timely antibiotic administration can save lives. One of the sepsis prediction algorithms based on EMR data uses a deep-learning approach and has shown satisfactory results in early prediction of sepsis. [17] Similar smart NLP algorithms, with the help of big data, can be used in patients presenting with chest pain or abdominal pain, for which diagnosis can be complicated, or for early risk prediction in a patient with stroke-like symptoms.

Smart emergency radiology can also become useful in the ED in the near future. One of the limiting factors in emergency radiology is the reporting time from the radiologist. This physical factor is a bottleneck that can be improved with the help of AI. There are well-documented AI programs that can be used in time-sensitive stroke treatment paradigm including infarct/hemorrhage detection or large vessel occlusion detection [18]. Similarly, new models are being developed for radiologic detection of traumatic injuries. Likewise, new ultrasound machines with diagnosis detection protocols can help ED physicians discover injuries or other abnormalities more quickly.

Emergency Telemedicine is another upcoming smart technology that can be used well within the ED. Telemedicine can be used to facilitate communication both within and outside of the hospital. For example, for a patient with acute stroke in the ED who needs a specialist consultation from a neurologist in a different location, telemedicine can be effectively used to assess the need for evaluation and intervention, thus reducing the time needed for the neurologist to physically examine the patient in person. [19] The same situation may arise for a patient at home, where emergency physician can remotely assess the patient before activating appropriate resources. This approach to evaluation will reduce ED overcrowding. Telemedicine services can be used together with the wearable technologies, as previously discussed, to better understand, and assess the emergency situation. Another important benefit is that this model creates a contactless environment, so the risk of infectious disease transmission is eliminated. [20] This reason alone was one of the biggest factors contributing to significant adoption of this technology during the current COVID-19 pandemic.

Computer vision-based AI to facilitate patient recognition, diagnosis, and monitoring is an emerging segment of smart technology and is worthy of discussion in this review. Computer vision-based AI has already shown to be able to do complex tasks such as self-driving a vehicle. Its adoption in the healthcare sector has been minimal. We can adopt this smart technology to recognize patients in the ED to monitor a patient's movements through the ED and various parts of the hospital, to reduce medication errors by recognizing the correct patient, and to provide automated patient authentication for various medicolegal requirements. Another aspect of computer vision-based technologies is to diagnose non-urgent conditions such as skin rashes. Computer vision-based analysis of skin lesions has shown good results [21] and can assist physicians to make the diagnosis. The same type of smart technology is being tested even to recognize the micro expressions of patients to predict their severity of illness for those who present to the ED.

Remote Photo Plethysm Ography (RPPG)-based monitoring of vital signs is another new technology using the same computer vision-based inputs [22] and needs minimal resources. It is contactless in nature uses an existing camera network and has an added advantage of reducing the risk of infectious disease spread. This technology can be used together with other AI algorithms such as motion tracking to monitor patient movements and even to detect patient falls or recognize emergency situations such as seizures. This use of smart technology will greatly reduce the need for on-site human-provided medical resources without compromising the quality of care during ED observation.

The last technology discussed here is revolutionary and may appear to be from a science fiction movie. An AI research team from Massachusetts Institute of Technology (MIT) has developed a remote contactless patient monitoring system using wireless signals. This system is able to monitor breathing, movement, and sleep patterns without interference to the patient. This smart technology has been used to monitor COVID-19 patients [23] and can be developed further to serve the ED population for monitoring, especially in an infectious disease crisis.

(iii) Post-ED follow-up

One of the biggest challenge of the current emergency care model is the lack of proper follow-up care when the patient is discharged home. As a result, many patients with mild to moderate symptoms are admitted to the hospital for observation. This admission cycle significantly contributes to an increased length of stay in the ED and an increased number of hospital admissions, leading to congestion of the whole healthcare system. Also, the lack of follow-up directly relates to readmission of patients to the ED and increases ED crowding. [24] Overall, lack of appropriate follow-up may contribute to poor patient outcomes.

Smart technologies can be used to address some of these challenges. All wearable technologies together with IoMT technologies previously discussed can be used to monitor

patients. Some monitoring can be automated based on the ED diagnosis, with the help of AI-driven mobile apps through a predesigned algorithm. This system coupled with a wearable vital sign monitor can provide a very robust follow-up for all patients discharged home. This approach will also create a continuous multiple timepoint triage system for patients in any emergency situation. If any monitored data or condition arises in the "gray area" that needs further input from a physician, the patient can be investigated through telemedicine services as discussed previously. Also, all of this information can be linked with community care service providers such as general practitioners for follow-up.

D. Smart emergency department operations

The current operations of the ED are physically located on the ED floor, and staffed either by the most senior emergency physician or a dedicated manager who walks around ED. With the use of smart technology the new model of ED operations will be based on electronic data and almost everything will be connected in the cloud space. This realignment will create a very large electronic network with software and data centers connected to this network. To ensure smooth operation of the ED, we must adopt the Network Operations Center (NOC) principles, which other industries use, to better achieve our objectives. [25]

This approach will create a new ED Operations (Ops) center, a hybrid model of NOC in which engineers work closely with the set of physicians and managers to manage and oversee the ED from one central location. Engineers will be responsible for tasks related to the smart technology. They will report important data to the physicians and managers. Then physicians can make decisions related to patient care and ED processes. In turn, ED managers can quickly make changes in the physical space of the ED to reflect these decisions and to monitor the operations remotely through video feeds. Also, physicians in the ED Ops center can provide necessary coordination among teams, provide telemedicine services, and supervise EMS. They can also take actions for the trigger points in the AI apps that indicate the need for human intervention. This ED Ops center model will be able to better manage a crisis situation in the future.

E. Challenges for implementing smart technologies in ED

Challenges to implementing smart technologies in the ED can be categorized mainly into two groups: One comprising of issues related to stakeholders, such as the physicians, health regulators, and patients, and the other related to technology itself.

On the human side, one of the biggest challenges is to inspire the physicians and health regulators to trust the use of technologies in the ED. Physicians are typically slow to adopt technologies or very hesitant to change their way of practice. [26] This caution is mainly due to a lack of understanding of the technology itself. This confusion leads to anxieties and feelings of insecurity; some physicians even feel technology slows down their work or reduces the physician–patient interactions. One of the biggest fears among physicians is that AI will eliminate their jobs in the near future. Moreover, a lack of research data on new technologies aggravates this fear. These challenges can be addressed by increasing the awareness and training for healthcare providers on these technologies. These technologies exist to facilitate physicians in making a correct decision.

Another important part for adoption of these new technologies is to establish a health regulatory framework. Over the past few years, the U.S. Food and Drug Administration (FDA) have taken important steps to update its regulatory framework to keep up with the rapidly advancing digital health sector. In 2017, the FDA released its Digital Health Innovation Action Plan to offer clarity about the agency's role in advancing safe and effective digital health technologies and to address its key provisions of the 21st Century Cures Act. [27] Much work on the regulation of "software-as-a-medical-device" is being done now.

The technical side of challenges exists mainly in the areas of data privacy and protection; the need for advanced technical skills; interoperability and interconnection among software; a lack of infrastructure in healthcare systems, including fast internet speeds and good cloud services; and a lack of mature technologies. Of all the obstacles, data-related challenges are the biggest barrier to widespread adoption. In addition, data compatibility is critical because healthcare entities might use different databases with various formats-how to unify the formats to make them compatible and to communicate is not easy. On the other hand, the smartness of the system depends on the quality and amount of data it receives and the ability to process the data; thus, weaknesses in the data would limit the smart capabilities of the overall system.

The maturity level of most of the technologies discussed herein is primarily in the development and adoption stages. Faster adoption together with careful data collection and analysis while the technology is being deployed will be an optimal way. Also, owing to immature state and origin of the software, most of these technologies shows poor interoperability and interconnection among software programs. [28]

Conclusion

Technology-driven smart emergency care brings numerous opportunities and challenges to the ED. To take advantage of these opportunities while simultaneously addressing the challenges to achieve smart and connected emergency care, we must push beyond our personal limits and move forward together in our collective effort as a healthcare ecosystem. To achieve this mammoth task, we must involve all the relevant stakeholders for wider discussion on the adoption, scaling, security, and improvements needed, so that we can all work towards this common goal. By doing so, the patients will benefit as they receive better care, while the specialty of emergency medicine will be better equipped to meet the challenges of the future.

Author Contribution

YK conceptualized and wrote the initial draft of the manuscript. YK, TBP and SP contributed to the review and editing of the manuscript. All the authors have approved the final draft of the manuscript.

Conflict of Interest

The authors have no conflict of interest

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