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REVIEW ARTICLE

Current Status and Future Perspectives on the Internet of Things in Oncology

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Abstract

The Internet of Things (IoT) has penetrated many aspects of everyday human life. The use of IoT in healthcare has been expanding over the past few years. In this review, we highlighted the current applications of IoT in the medical literature, along with the challenges and opportunities. IoT use mainly involves sensors and wearables, with potential applications in improving the quality of life, personal health monitoring, and diagnosis of diseases. Our literature review highlights that the current main application studied in the literature is physical activity tracking. In addition, we discuss the current technologies that would help IoT-enabled devices achieve safe, quick, and meaningful data transfer. These technologies include machine learning/artificial intelligence, 5G, and blockchain. Data on current IoT-enabled devices are still limited, and future research should address these devices' effect on patients' outcomes and the methods by which their integration in healthcare will avoid increasing costs.

Keywords: Cancer, Internet of medical things, Oncology, Wearables

1. Introduction

Healthcare is expected to embrace technological advancements to transform into a patient-centered system [1]. Many promising areas have contributed to such a transformation, including Internet of Things (IoT) technologies, next-generation communication technology such as 5G, secure healthcare data storage such as blockchain, and artificial intelligence/machine learning/deep learning (AI/ML/DL). A convergence of several key technologies such as the IoT, cognitive computing, machine learning, and big data shows promising potential in cancer care [2]. IoT, including wearable and sensors, can monitor cancer patients with data that might impact clinical outcomes [3]. Increasing numbers of medical devices to monitor vital signs (heart rate, blood pressure, oxygen saturation, and temperature), glucose, activity, cardiac rhythm using electrocardiogram (EKG), and intelligent home monitoring sensors are connected to the internet, that is, IoT enabled.

IoT is a network of physical objects, machines, and other devices that enables connectivity and communications to exchange data for intelligent applications and services [4]. IoTs have penetrated most

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aspects of everyday human life, given their utilization as digital biomarkers of passive sensors [5,6]. IoT devices are increasingly being invested in the medical field, particularly in monitoring predetermined health indicators (e.g., vital signs, physical activity, etc.) [7,8]. This has led to the parallel expansion of medical literature discussing the implementation of IoT in healthcare. Implementing these advancements in future healthcare might help deliver patient-centered care and increase the expanding healthcare system's efficiency. Through seamless, secure integration of wireless technologies, the IoT systems can facilitate cancer care, whether in medical procedures, point-of-care testing, chemotherapy treatments, monitoring, alerting, or scheduling follow-ups. In this review article, we aim to highlight the current IoT ecosystem in cancer care.

2. Current advances in data sharing and analysis

The goal of IoT devices is to collect data about patients that would be able to improve clinical outcomes and patients' quality of life (QoL). To enhance IoT devices' ability and use the data collected in a meaningful and secure fashion, additional measures must be taken to secure and facilitate the transmission of any captured data [9]. The connected health network requires the privacy, security, and integrity of patient data. As data are captured in IoT devices, measures must be taken to apply appropriate security and privacy mechanisms. Thus, other technologies are needed to support and expand on the work of IoT devices. The potential advantages and disadvantages of some of these technologies are summarized in Table 1. For instance, the connectivity of IoT devices to the internet is of crucial importance, including the use of Wi-Fi and cellular connection. 5G represents the next step in cellular networks' evolution and is not just an extension to the 4G network as it combines multiple technologies, including 4G and Wi-Fi technologies [4]. It is distinguished by significantly high data rates, lower error rates, and fewer delays, all of which have profound implications on 5G's healthcare and telemedicine [10].

Moreover, given the sensitivity of patients' data, technologies that can increase data safety are vital in ensuring patient's privacy with the implementation of IoT devices. Blockchain is one of the newer technologies which was initially developed as a ledgering technology for cryptocurrency systems such as bitcoin [11,12]. It is unique in that it avoids having a third party in information sharing. This lack of third party results in quicker, safer, and cheaper communication between the different parties. This technology is relevant to healthcare as it can store sensitive data in a secure and tamper-resistant environment, easily accessible to authorized personnel in large networks.

Furthermore, selected amounts of data could be shared with relevant stakeholders, such as insurance companies. Multiple studies and tools have been developed using blockchain technology in healthcare. For instance, in partnership with the Open Health Network, the American Heart Association is developing a product called "PatientSphere," a blockchain-based data platform utilizing AI to deliver treatment plans and exercise tips to patients [13].

Table 1. New technologies and their potential advantages and disadvantages.

Technology	Potential advantages	Potential disadvantages
Internet of Things	Improved monitoring	Privacy, security, and reliability issues
	Increased efficiency	Overdiagnosis and increasing patient's anxiety
	Increased accessibility to care	Dehumanizing care
	Improved quality of life	Patient participation and proper use
	Increased preventative care	Device and system failure
	Increased access to data for research	Standards and integration
	Potential decreased costs	Potential increased costs
Blockchain	Increased transparency	Logistical challenges
	Improved data security and privacy	Misunderstanding and mistrust of technology
	Empowering patients	Privacy and security issues
	Increased efficiency	Increased costs (?)
Edge Computing	Reduced costs	Limited data access
	Reduced latency	Additional privacy and security issues
	Improved scalability and reliability	Need for network connectivity
AI/ML/DL	Robust analysis of data	Need big data
	Increased efficiency of healthcare	Privacy and security issues
	Improve many aspects of healthcare, including diagnostics and therapeutics	Dehumanizing care
		Algorithmic uncertainty and bias

Note. AI/ML/DL = artificial intelligence/machine learning/deep learning.

Other technologies that improve efficiency and safety are developed or being developed, including edge computing. The concept of edge computing was designed to ensure that servers/devices at the edges can process cancer care data, shifting some processing from the "clouds" closer to where the data is generated, that is, the hospital or cancer patient's home [14]. This shift allows for reduced costs, latency, and can increase data security and privacy.

However, the technologies and newer approaches that have attracted the most attention in medical literature in recent years are machine learning and AI. AI and ML are thought to play an essential role in the future of healthcare. These technologies are based on the machines' ability to perform tasks that usually require human intelligence [15]. These tools can also process tremendous amounts of data, generating countless diagnostic and prognostic applications in medicine. The literature of AI/ML in medicine has been growing exponentially, with possible oncology applications and all other areas of medicine [16].

Machine learning tools, along with other advancing technologies, can expand IoT tools' potential and capabilities. The usage of IoT sensors can support the collection of patient-generated health data (PGHD) [17,18], which can be utilized to create models (using AI and ML) that can be used to improve clinical outcomes. For instance, Machorro-Cano et al. [19] proposed an ML and IoT-Based Smart Health Platform that monitors overweight and obesity in patients from patient-reported outcomes (PROs) and PGHD data and provided recommendations and feedback. Whether such systems will improve outcomes is a question that future research agendas should address. Fig. 1 illustrates the interaction between these different technologies.

3. Current literature on IoT and cancers

3.1. IoT-enabled physical activity trackers

Physical activity trackers are the most common use of IoT that is reported in the literature. These trackers collect data about patients' physical activity, which researchers can access using the internet. There are multiple examples in the literature of physical activity trackers and the relationship between moderate to vigorous physical activity (MVPA) and subsequent improvement in QoL. However, their effect and value are not consistently reported. For instance, ACTIVATE [20] is a randomized, open-label trial involving 83 stages I–III breast cancer patients. The intervention included using actigraphy technology, which the researchers accessed via an application programming interface, behavioral feedback, and coaching session. Results illustrated the significant increase in MVPA minutes per week (mean difference = 69 min/wk; Confidence Interval (CI), 22–116) in the intervention

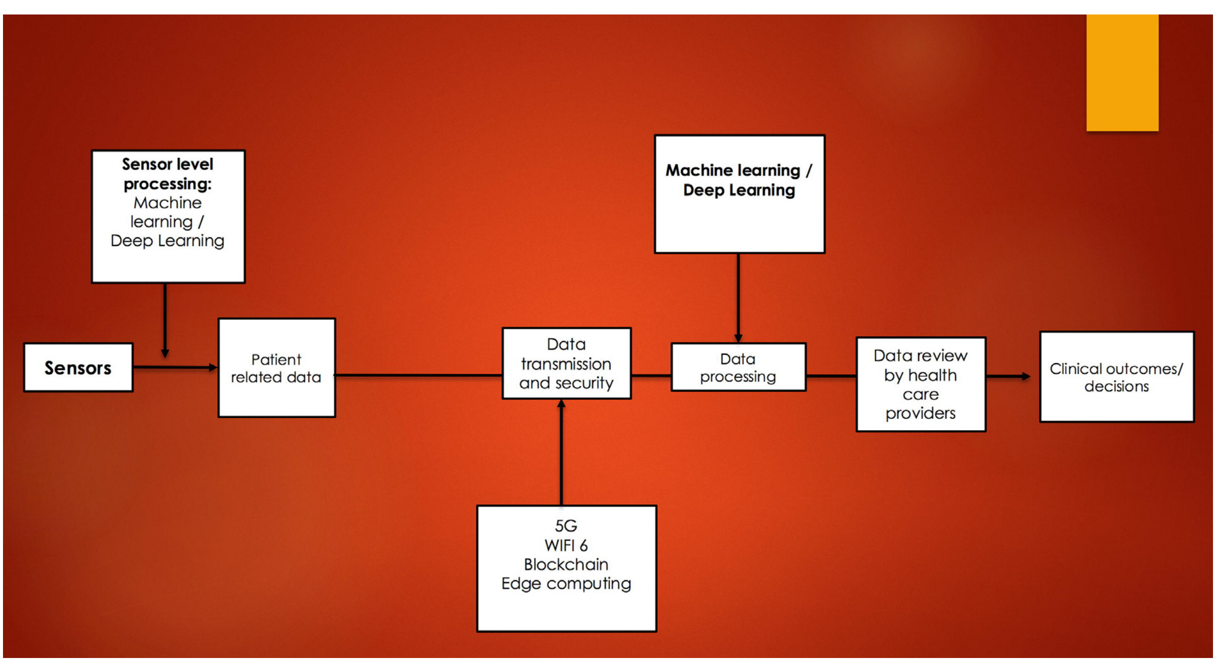

Fig. 1. Schematic illustration of the interaction between different technologies and Internet of Things (IoT).

group. Meanwhile, Pope et al. [21], in a pilot study involving 30 breast cancer patients using fitness trackers (only the intervention group) and Facebook group (both intervention and control groups), showed increased activity in both groups. No significant differences were found in outcomes.

Like studies in breast cancer, most studies involving IoT-enabled wearables in other cancers involved physical activity monitoring. Some studies suggested possible behavioral changes that might be attributed to these technologies. For example, one study involving 68 colorectal and endometrial cancer survivors showed an increase of 45 minutes of MVPA per week in the interventional (wearables) group; however, the interventional group also received sessions and phone calls [22]. However, the behavior change could be attributed to wearables alone rather than the IoT component or the fact that the patients receiving the intervention received more education.

Limitations and challenges of using wearables in breast cancer were also highlighted in the literature. In a prospective study involving 65 breast cancer patients on chemotherapy, it was noted that 16.9% never synced the device, indicating the need for easy-to-use IoT. During the study's 9-month duration, the mean percentage of days the patient used the Fitbit for more than 10 hours (referred to as valid days) was 44.5%. This shows that low compliance is a challenge facing these devices, which, if not addressed, may hinder the full potential of these tools [23].

3.2. *Other daily parameters and monitoring QoL*

QoL is a crucial factor to consider in managing patients with cancers. The primary parameter collected was physical activity, as discussed above. However, other biometric parameters collected included: vitals (heart rate, blood pressure, etc.), weight, and symptoms tracking. Multiple articles have attempted to correlate these parameters to QoL, including physical activity [24]. For instance, the CYCORE (CYberinfrastructure for COmparative Effectiveness REsearch) group studied the use of technology, including sensors and wearables, with the help of IoT to improve QoL in head and neck cancers [25]. The sensors collected information through mobile applications, such as blood pressure, weight, and daily symptoms.

However, the potential of IoT is not limited to the collection of these parameters. For example, wearables collected information regarding depression, which was sent to their physicians via the internet. These wearables achieved a moderate correlation to the validated depression scales [26]. The development of similar tools might help us to understand and follow-up psychological QoL in cancer patients.

3.3. *Diagnosis*

It is important to note that IoT and sensors are not limited to wrist wearables; many sensors have been developed, including E-textile. For instance, wearables augmented with machine learning in cancer were used in developing iTBra, helping to track the risk of breast cancer and might lead to early detection [27].

Additionally, multiple articles have reported using IoT technology and AI tools to diagnose and detect lung cancer. Using data from computerized tomography (CT) scans, wearable sensors, and deep learning tools, Masood et al. [28] proposed a computer-assisted diagnosis system to predict lung cancer; however, the accuracy was about 80%. Other examples in the literature using different AI algorithms and IoT tools for continuous monitoring were reported with high accuracy [29,30]. These studies are not yet validated clinically, and more studies will be needed to prove their impact on clinical outcomes; however, they reflect the potential of IoT.

4. IoT: Opportunities and challenges for cancer patients and survivors

4.1. *Opportunities for IoT and wearables in cancer care*

IoT-enabled devices introduce multiple opportunities in the medical field. We believe three opportunities could improve cancer care: health improvement, increased access and generating large numbers of data points and big data.

Changing patients' behavior and lifestyle might be one of the possible roles that IoT could accomplish. Some studies have shown increased activity levels and the average daily steps in patients using wearables [31,32]. Increased activity was related to many notable health benefits, including decreased body mass index, improved recovery, and lower readmission rates [31,33]. However, it is unclear whether IoT will provide any additional value to the possible behavioral changes driven by wearables and self-motivation.

Despite this, IoT and other technologies may improve access to healthcare in areas where medical care is underdeveloped [34]. Personalized health monitoring and mobile health have been suggested to increase access to equitable healthcare, making it easier for residents of rural areas to receive the care they need [34,35]. However, more data are required in order to prove this, and cost-efficiency studies are needed.

Additionally, wearables are data-generating devices, which means a potentially massive amount of data collected (with consent) to be utilized via machine learning applications [36]. AI-enabled wearables can expand functionality and directly improve healthcare with a wide range of possible applications.

4.2. *Privacy and cybersecurity issues*

Multiple challenges arise with the implementation of IoT, particularly wearables, in the field of oncology. For instance, data-generated privacy is an issue that might be of concern to patients [37]. The healthcare information is stored in the IoT or propagated to cloud-based servers or blockchains. Despite advancements, these technologies are still vulnerable to violations [38]. This could be detrimental to clinical care and may create resistance to adopting future technological advancements within the healthcare community. An optimum medical IoT ecosystem requires specific essential components, including data integrity, confidentiality, and availability [8]. Multiple reviews have provided a comprehensive overview of medical IoT devices' security and privacy issues and possible solutions [39,40]. Additionally, other functionality and policies are needed to ensure privacy by properly sharing data and rules for storing and eventually disposing of the data.

These tools' accuracy and reliability are also questionable, as many have a large margin of error [41]. The exponential increase in these tools, many of which are not yet approved by regulatory bodies, could introduce misconceptions. Thus, it is crucial to review these tools with patients, ensuring they understand the limitations of IoT tools and their roles.

5. Patient's perspective on the use of wearables and IoT technologies

Wearables and IoT usage are expanding, and their capabilities to augment healthcare is growing exponentially. However, these practices and technologies must be developed to be able to achieve patient-centered care. Multiple articles have reported the positive attitude of patients toward these tools. For instance, in a study involving more than 1000 patients with various chronic medical problems, only 3% of patients felt that wearable biometric monitoring devices (BMDs) have more negative effects [42]. However, 20% of patients raised concerns about the risk of hacking, and more than 30% elicited the possible dehumanization of care. This highlights the importance of addressing patients' concerns to optimize the use of these technologies [43].

Current cancer literature generally shows positive feedback from patients regarding different wearable technologies, particularly breast cancer patients. Nguyen et al. [44] showed that breast cancer patients accepted activity trackers and provided feasible and cost-effective strategies to improve physical inactivity and sedentary behavior interventions. This was supported by other studies [45,46], showing the opportunity to create personalized and customized interventions that meet breast cancer survivors' personal preferences in implementing technology into their care. Another study by Rosenberg et al. [47] showed that prostate cancer patients found fitness trackers comfortable and easy to use. The development of these tools will need to be considered from a patient's perspective to ensure a patient-centered approach.

6. Providers' perspectives on IoT and wearable use

Technological developments are quickly integrated into the medical field, which may be difficult for some providers to adapt to, leading to resistance in certain circumstances. For instance, multiple studies have shown physicians' resistance to adopt electronic health records (EHRs), particularly in smaller practices [47,48]. A study [49] involving 1406 healthcare providers illustrated that consumers have a significantly higher preference for new technologies for medical diagnosis than providers (39.66% vs. 13.80%, $p < .001$). Wearables and IoT introduce the possibility of patients' accessing their information, which physicians might be uneasy about given the possible increased anxiety in patients [49].

7. Conclusions and future scope

As illustrated in Section 'Current literature on IoT and cancers', the current data are limited by multiple factors. Although many of the studies mentioned above are interventional and prospective in design, the number of patients is usually low, and many studies are in the pilot stages, making it challenging to recommend these tools using an evidence-based approach. The nature of wearables/sensors was a limiting factor in achieving blinding in randomized controlled trials using IoT-enabled wearable technology. In addition to that, wearables are usually a component of a comprehensive program, which introduces many confounding elements limiting the researchers' ability to deduce accurate conclusions on the effect and value of wearable devices.

The technology use reported in the literature is also limited; most articles discuss the use of wearables in physical activity. We believe that the use of IoT in research should expand to involve more applications. This is expected to increase particularly with the changes that the COVID-19 pandemic has imposed. The pandemic has transformed the field of telemedicine. A study has reported an increase in telemedicine visits of almost 7 times in March and April 2020 [50]. Thus, several applications of IoT might help in delivering quality healthcare even in times of pandemics [51]. There is also a need for more studies that utilize the power of AI and ML to use these data to develop models that can aid our clinical decision-making, as wearables can accurately reflect PROs.

Additionally, the main question is the value of gathering patients' data on clinical outcomes. Research should be directed in using these technologies in collecting data that are meaningful enough to lead to better clinical outcomes. The current literature fails to answer this question. Thus, future literature will need to investigate these benefits and possible disadvantages, including overdiagnosis. The integration of these technologies is further complicated by lack of standards; challenges in verification/analytical validation/clinical validation (V3) of the devices; challenges in determining what clinicians should be reacting to and how these data should be integrated and displayed within an EHR; and challenges in deciding which parts of the healthcare team should deliver responses to the alerts.

This review illustrates the potential uses of IoT-enabled devices/sensors in oncology through the current literature, extending from aiding in the diagnosis to improving life quality. The discussion above illustrates the ongoing efforts to implement IoT-enabled devices/sensors in cancer care. The possible roles and potential of IoT extend beyond wearables.

Although this is a growing area with enormous potential, studies still need to prove these tools' impact on clinical outcomes. The possible effects of these simple tools on QoL, for instance, might change the current standards of care. In this review, we also highlight the importance of developing patient-oriented, physician-friendly devices and improving clinical outcomes.

Authorship contributions

OR, EH, MM, RA, IM and SKH wrote the first draft of the manuscript. All authors vouch for the accuracy and contents of the manuscript. All authors approved the final version of the draft.

Declaration of Competing Interest

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