Chatbot for Healthcare and Oncology Applications using Artificial Intelligence and Machine Learning

Lu Xu, Leslie Sanders, Kay Li, James C L Chow

Submitted to: JMIR Cancer
on: February 09, 2021

Disclaimer: © The authors. All rights reserved. This is a privileged document currently under peer-review/community review. Authors have provided JMIR Publications with an exclusive license to publish this preprint on it's website for review purposes only. While the final peer-reviewed paper may be licensed under a CC BY license on publication, at this stage authors and publisher expressively prohibit redistribution of this draft paper other than for review purposes.
# Table of Contents

**Original Manuscript**

**Supplementary Files**

**Figures**

- Figure 1
- Figure 2
Chatbot for Healthcare and Oncology Applications using Artificial Intelligence and Machine Learning

Lu Xu¹ MEng; Leslie Sanders² PhD; Kay Li³ PhD; James C L Chow⁴ PhD

¹Institute of Biomedical Engineering, University of Toronto, Toronto and Medical Biophysics Department, Western University London CA
²Department of Humanities, York University Toronto CA
³Department of English, York University Toronto CA
⁴Radiation Medicine Program, Princess Margaret Cancer Centre, University Health Network and Department of Radiation Oncology, University of Toronto Toronto CA

Corresponding Author:
James C L Chow PhD
Radiation Medicine Program, Princess Margaret Cancer Centre, University Health Network and Department of Radiation Oncology, University of Toronto
7/F, RMP/PM/UHN
700 University Avenue
Toronto
CA

Abstract

Background: Chatbot is a timely topic applied in various fields, including medicine and healthcare, for human-like knowledge transfer and communication. Machine learning (ML), a subset of artificial intelligence (AI), has been proven particularly applicable in healthcare with the ability for complex dialogue management and conversational flexibility.

Objective: This review article reports on the recent advances and applications of chatbot technology in medicine.

Methods: To provide a comprehensive background, a brief historical overview along with the developmental progress and design characteristics are first introduced. The focus will be in regards to cancer therapy with in-depth discussions and examples for diagnosis, treatment, monitoring, patient support, workflow efficiency, and health promotion. Similar with all forms of technology, risks and challenges will arise before their universal adoption in healthcare. Thus, this paper will explore limitations and areas of concern highlighting ethical, moral, security, technical, regulatory standards, and evaluation issues to explain the hesitancy of implementation.

Results: Even after addressing these issues and establishing the safety or efficacy of chatbots, the human element in healthcare will not be replaceable. Therefore, chatbots have the potential to be integrated into clinical practice by working alongside health practitioners to reduce costs, refine workflow efficiencies, and improve patient outcomes. Other applications in pandemic support, global health, and education are yet to be fully explored.

Conclusions: Further research and interdisciplinary collaboration could advance this technology to dramatically improve the quality of care for patients, rebalance workload for clinicians, and revolutionize the practice of medicine.

(JMIR Preprints 09/02/2021:27850)
DOI: https://doi.org/10.2196/preprints.27850

Preprint Settings

1) Would you like to publish your submitted manuscript as preprint?
   Yes, please make my preprint PDF available to anyone at any time (Recommended).
   Please make my preprint PDF available only to logged-in users; I understand that my title and abstract will remain visible to all users.
   Only make the preprint title and abstract visible.
   No, I do not wish to publish my submitted manuscript as a preprint.

2) If accepted for publication in a JMIR journal, would you like the PDF to be visible to the public?
   Yes, please make my accepted manuscript PDF available to anyone at any time (Recommended).

https://preprints.jmir.org/preprint/27850 [unpublished, peer-reviewed preprint]
Yes, but please make my accepted manuscript PDF available only to logged-in users; I understand that the title and abstract will remain visible.

Yes, but only make the title and abstract visible (see Important note, above). I understand that if I later pay to participate in the PubMed Now! service, my accepted manuscript PDF will automatically be made openly available.
Chatbot for Healthcare and Oncology Applications using Artificial Intelligence and Machine Learning

Lu Xu1,2, Leslie Sanders3, Kay Li4, and James C. L. Chow5,6

1 Institute of Biomedical Engineering, University of Toronto, Toronto, Canada
2 Medical Biophysics, Western University, London, Canada
3 Department of Humanities, York University, Toronto, Canada
4 Department of English, York University, Toronto, Canada
5 Radiation Medicine Program, Princess Margaret Cancer Centre, University Health Network, Toronto, Canada
6 Department of Radiation Oncology, University of Toronto, Toronto, Canada

E-mail: james.chow@rmp.uhn.ca

Received xxxxxx
Accepted for publication xxxxxx
Published xxxxxx

Abstract

**Background:** Chatbot is a timely topic applied in various fields, including medicine and healthcare, for human-like knowledge transfer and communication. Machine learning (ML), a subset of artificial intelligence (AI), has been proven particularly applicable in healthcare with the ability for complex dialogue management and conversational flexibility.

**Objective:** This review article reports on the recent advances and current trends of chatbot technology in medicine. A brief historical overview along with the developmental progress and design characteristics are first introduced. The focus will be in regards to cancer therapy with in-depth discussions and examples of diagnosis, treatment, monitoring, patient support, workflow efficiency, and health promotion. Additionally, this paper will explore limitations and areas of concern highlighting ethical, moral, security, technical, regulatory standards, and evaluation issues to explain the hesitancy of implementation.

**Methods:** A search of literature published in the last 20 years was conducted through IEEE Xplore, PubMed, Web of Science, Scopus, and OVID databases. Screening of chatbots was guided from the open-access Botlist directory for healthcare applications and further divided according to the following criteria: diagnosis, treatment, monitoring, support, workflow, health promotion.

**Results:** Even after addressing these issues and establishing the safety or efficacy of chatbots, the human element in healthcare will not be replaceable. Therefore, chatbots have the potential to be integrated into clinical practice by working alongside health practitioners to reduce costs, refine workflow efficiencies, and improve patient outcomes. Other applications in pandemic support, global health, and education are yet to be fully explored.

**Conclusion:** Further research and interdisciplinary collaboration could advance this technology to dramatically improve the quality of care for patients, rebalance workload for clinicians, and revolutionize the practice of medicine.

**Keywords:** Chatbot, Artificial intelligence; Machine learning; Health; Medicine; Communication;
Introduction

Artificial intelligence (AI) is at the forefront of transforming numerous aspects of our lives by modifying the way we analyse information and improve decision-making through problem-solving, reasoning, and learning. Machine learning (ML) is a subset of AI that improves its performance based on data provided to a generic algorithm from experience, rather than defining rules in traditional approaches [1]. Advancements in ML have provided benefits in terms of accuracy, decision making, quick processing, cost-effectiveness, and handling complex data [2]. Chatbots, also known as chatter robots, smart bots, conversational agents, digital assistants, or intellectual agents, are prime examples of an AI system that has evolved from ML. The Oxford dictionary defines a chatbot as "a computer program that can hold a conversation with a person, usually over the internet". They can also be physical entities designed to socially interact with humans or other robots. Pre-determined responses are then generated by analysing user input, on text or spoken ground, and accessing relevant knowledge [3]. Problems arise when dealing with more complex situations in dynamic environments and managing social conversational practices according to specific contexts and unique communication strategies [4].

Given these effectual benefits described above, it is not a surprise that chatbots have rapidly evolved these past two decades and integrated themselves into numerous fields, such as entertainment, travel, gaming, robotics, and security. Chatbots have been proven particularly applicable in various healthcare applications that usually involve face-to-face interactions. With their ability for complex dialogue management and conversational flexibility, integration of chatbot technology into clinical practice may reduce costs, refine workflow efficiencies, and improve patient outcomes [5]. A Web-based, self-report survey examining physicians’ perspectives found positive benefits of healthcare chatbots in managing one’s own health, improved physical, psychological, and behavioural outcomes, and most notably for administrative purposes [6]. In light of the opportunities provided by this relatively new technology, potential limitations and areas for concern may arise that could potentially harm users. Concerns about accuracy, cyber-security, lack of empathy, and technological maturity are reported as potential factors associated with the delay in chatbot acceptability or integration into healthcare [7].

This narrative review paper reports on the healthcare applications for chatbots with a focus on cancer therapy. The rest of the paper is organized as follows. We first introduce the developmental progress with a general overview of the architecture, design concepts, and types of chatbots. The main results section focuses on the role that chatbots play in areas related to oncology such as, diagnosis, treatment, monitoring, support, workflow efficiency, and health promotion. The discussion section analyses potential limitations and concerns for successful implementation while addressing future applications and research topics.

Methods

This review focuses on articles from peer-reviewed journals and conference proceedings. The following databases were searched from October to December 2020 for relevant and current studies from 2000 to 2020: IEEE Xplore, PubMed, Web of Science, Scopus, and OVID. The literature search used the following key terms (‘chatbot’, ‘chatter robot’, ‘conversational agent’, ‘artificial intelligence’, ‘machine learning’). For further refinement, these key terms were combined with more specific terms aligned with the focus of the article. This
included ‘healthcare’, ‘cancer therapy’, ‘oncology’, ‘diagnosis’, ‘treatment’, ‘radiation therapy’, ‘radiotherapy’. The searches were not limited by language or study design. Letters and technical reports were excluded from the search. The full list of sources and search strategy is available from the authors.

Screening of chatbots was guided by a systematic review process from the Botlist directory during the period of January 2021. This directory was chosen because it was open-access, categorized the chatbots under many different categories (ie. healthcare, communication, entertainment, etc.), and contained many commonly used messaging services (ie. Facebook Messenger, Discord, Slack, Kik, Skype). A total of 78 chatbots were identified for healthcare application and further divided according to following criteria: diagnosis, treatment, monitoring, support, workflow, health promotion. It should be noted that using the health filters from a web directory limits the results to searching strategy and marketing label. Thus, results from equivalent studies may differ when repeated.

Results
Chatbot History and Evolution

The idea of a chatbot was first introduced in 1950 when Alan Turing proposed the question, “Can machines think?” [8]. The earliest forms were designed to pass the Turing test and mimic human conversations as much as possible. In 1966, Eliza was the first known chatbot developed that acted as a psychotherapist using pattern matching and template-based responses to converse in a question format [9]. Improvements were made to build a more human-like and personalized entity by incorporating a personality in PARRY that simulated a paranoid patient [10]. One of the most well-known chatbot is ALICE, developed in 1995, that uses a pattern-matching technique to retrieve example sentences from output templates and avoid inappropriate responses [11]. A renewed interest in artificial intelligence and advances in machine learning have led to the growing use and availability of chatbots in various fields [12]. SmarterChild [13] became widely accessible through messenger applications followed by more familiar virtual assistants using voice-activated systems, such as Apple Siri, Amazon Alexa, Google Assistant, or Microsoft Cortana. Based on our analysis (Figure 1), the most popular development of chatbots for healthcare purposes are diagnostics, patient support (ie. mental health counselling), and health promotion. Some of these applications will be further explored in the following section for cancer applications.
Figure 1. Search and screening for healthcare chatbots. Applications using more than one platform are included.

**Chatbot General Architecture**

Although there are a variety of techniques for the development of chatbots, the general layout is relatively straightforward. As a computer application that uses machine learning to mimic human conversation, the underlying concept is similar between all types with four essential stages (input processing, input understanding, response generation, and response selection) [14]. A simplified general chatbot architecture is illustrated below (Figure 2). First, the user makes a request, in text or speech format, that is received and interpreted by the chatbot. From there, the processed information could be remembered or more details could be requested for clarification. After the request is understood, the requested actions are performed and the data of interest is retrieved from the database or external sources [15].
Chatbot Types

With the vast amount of algorithms, tools, and platforms available, understanding the different types and end purpose of these chatbots will assist developers when choosing the optimal tools when designing them to fit the specific needs of users. These categories are not exclusive as chatbots may possess multiple characteristics making the process more variable. The five main types are described below [15]. Table 1 describes some examples of the recommended applications for each type of chatbot, but are not limited to the ones specified.

Knowledge domain classification is based on accessible knowledge or the data used to train the chatbot. Under this category are the open domain for general topics and the closed domain focusing on more specific information. Service provided classification is dependent on the sentimental proximity to the user and the amount of intimate interaction dependent on the task performed. This can be further divided into interpersonal providing services to transmit information, intrapersonal for companionship or personal support to humans, and inter-agent to communicate with other chatbots [14]. The next classification is based on goals with the aim to achieve, sub-divided to informative, conversational, and task-based. Response generation chatbots, further classified as rule-based, retrieval-based, and generative, account for the process of analyzing inputs and generating responses [16]. Lastly, the human-aided classification incorporates human computation which provides more flexibility and robustness, but lacks the speed to accommodate more requests [17].

Table 1. Recommended healthcare applications for the different types of chatbots.

| Type of Chatbot     | Recommended Applications                                                                 |
|---------------------|------------------------------------------------------------------------------------------|
| Knowledge Domain    | *Open:* Responding to more general and broader topics that can be easily searched within databases. May be the preferred chatbot type for routine symptom screening, connecting to providers/services, or health promotion applications. |
## Chatbots in Cancer Therapy

Cancer has become a major health crisis and is the second leading cause of death in the US [18]. The exponentially increasing number of cancer patients each year may be a combination of carcinogens in the environment and improved quality of care. The latter aspect could explain why cancer is slowly becoming a chronic disease that is manageable over time [19]. The added life expectancy poses new challenges for both patients and the healthcare team. For example, many patients now require extended at-home support and monitoring while healthcare workers deal with the increased workload. Although clinician’s knowledge-base has exploded...
in the use of scientific evidence to guide decision making, there are still many other facets to the quality of care that has yet to catch up. Key areas of focus are the safety, effectiveness, timeliness, efficiency, equitability, and patient-centered care [20].

Chatbots have the potential to address many of the current concerns of cancer care mentioned above. This includes the triple aim of healthcare that encompasses improving the experience of care, improving the health of populations, and reducing per capita costs [21]. Chatbots can improve the quality or experience of care by providing efficient, equitable, and personalized medical services. We can think of them as intermediaries with physicians to facilitate history taking of sensitive and intimate information before consultations. They could also be thought of as decision aids that deliver regular feedback on disease progression and treatment reaction to help clinicians better understand individual conditions. Preventative measures of cancer have become a global priority because early detection and treatment alone have not been effective in eliminating this disease [22]. Physical, psychological, and behaviour improvements of underserved or vulnerable populations may even be possible through chatbots because they are so readily accessible through common messaging platforms. Health promotion usage, such as lifestyle coaching, healthy eating, and smoking cessation, has been one of the most common chatbots according to our search. Additionally, chatbots could help save a significant amount of healthcare costs and resources. Newer therapeutic innovations have come with a heavy price tag and out-of-pocket expenses have placed a significant strain on patients’ financial well-being [23]. With chatbots implemented into cancer care, consultations for minor health concerns may be avoided which allows clinicians to spend more time with patients who need their attention the most. Costs may also be reduced by delivering medical services more efficiently. For example, the workflow could be streamlined by assisting physicians in administrative tasks, such as scheduling appointments, providing medical information, or locating clinics.

With the rapidly increasing applications of chatbots to healthcare, this section will explore several areas of development and innovation in cancer care. Various examples of current chatbots provided below will illustrate their ability to tackle the triple aim of healthcare. The specific use case of chatbots in oncology with examples of actual products and proposed designs are outlined below (Table 1).

| Use Case                                      | Application                  | Chatbot                  | Function                                           |
|-----------------------------------------------|------------------------------|--------------------------|----------------------------------------------------|
| Screening and Diagnosis                       | Imaging diagnostic           | Medical Sieve[24]        | Examines radiological images to aid clinicians with diagnosis |
|                                               | Symptom screening            | Quro [25]                | Pre-synopsis based on symptoms and history to predict user conditions |
|                                               |                              | Buoy Health [26]         | Assists in identifying the cause of illnesses and provides medical advice |
|                                               |                              | Harshitha breast cancer screening [27] | Dialog flow to give an initial analysis of breast cancer symptoms |
|                                               |                              | Babylon [28]             | Symptom checker                                    |
|                                               |                              | Your.md [28]             | Symptom checker                                    |
|                                               |                              | Ada [28]                 | Symptom checker                                    |
| Treatment          | Hereditary assessment | Gathers family history information at the population level to determine the risk of hereditary cancer |
|--------------------|-----------------------|--------------------------------------------------------------------------------------------------|
| Patient treatment recommendation | Mathew [30] | Identifies symptoms, predicts the disease using a symptom-disease dataset, and recommends a suitable treatment |
|                    | Madhu [31] | Provides list of available treatments for various diseases, informs the user of the composition and prescribed use of the medications |
| Connecting patients with providers/resourses | Divya [32] | Engages patients about their symptoms to provide a personalized diagnosis and connects with appropriate medical service |
|                    | Rarhi [33] | Provides a diagnosis based on symptoms, measure the seriousness, and connect with a physician |
| Physician treatment planning | Watson for Oncology [34] | Examines data from records and medical notes to generate an evidence-based treatment plan for oncologists |
| Monitoring         | Remote patient monitoring | Provide access to care instructions and educational information |
|                    | STREAMD [35] | Provide access to care instructions and educational information |
|                    | Conversa [35] | Provide access to care instructions and educational information |
|                    | Memora Health [35] | Provide access to care instructions and educational information |
|                    | AiCure [36] | Coach patients in managing their condition and adhering to instructions |
|                    | Infinity [37] | Assess health outcomes and impact of phone-based monitoring for cancer patients 65 + years |
|                    | Vik [38, 39] | Addresses patient’s daily needs and concerns |
| Support            | Counselling | Vivobot [40] Cognitive and behavioural intervention for positive psychology skills and promote well-being |
| Emotional support  | Youper [26] | Daily emotional support and mental health tracking |
|                    | Wysa [26] | Daily emotional support and mental health tracking |
|                    | Replika [26] | Daily emotional support and mental health tracking |
| Workflow | Administration | Sense.ly [42] | Assist in monitoring appointments, manage patients’ conditions, and suggest therapies |
| --- | --- | --- | --- |
|  |  | Careskore [42] | Tracks vitals and anticipates the need for hospital admissions |
|  |  | Mandy [43] | Assists healthcare staff by automating the patient intake process |
| Patient encounter | HOLMeS [44] | Support diagnosis, choose the proper treatment pathway, and provide prevention check-ups |
| Health Promotion | General lifestyle coaching | SWITCHes [45] | Track patients’ progress, provides insight to physicians, and suggests suitable activities |
|  |  | CoachAI [46] | Track patients’ progress, provides insight to physicians, and suggests suitable activities |
|  |  | WeightMentor [47] | Provides self-help motivation for weight loss maintenance and allows for open conversation |
| Healthy eating | Health Hero [48] | Guides in making informed decisions around food choices to change unhealthy eating habits |
|  | Tasteful Bot [48] | Guides in making informed decisions around food choices to change unhealthy eating habits |
|  | Forksy [48] | Guides in making informed decisions around food choices to change unhealthy eating habits |
|  | SLOWbot [49] | Guides in making informed decisions around food choices to change unhealthy eating habits |
| Smoking cessation | SMAG [50] | Cognitive behaviour therapy |
|  | Bella [51] | Coach to help quit smoking |

**Diagnostics and Screening**

Receiving an accurate diagnosis is critical for appropriate care to be administered. In terms of cancer diagnostics, AI-based computer vision is a function often used in chatbots that could recognize subtle patterns from images. This would increase physicians’ confidence when
identifying cancer types because even highly trained individuals may not always agree on the diagnosis [52]. Studies have shown that the interpretation of medical images for the diagnosis of tumours performs equally as well or better with AI compared to experts [53-56]. Additionally, automated diagnosis may be useful when there are not enough specialists to review images. This was made possible through deep learning algorithms in combination with the increasing availability of databases for the tasks of detection, segmentation, and classification [57]. For example, Medical Sieve is a chatbot that examines radiological images to aid and communicate with cardiologists and radiologists to identify issues quickly and reliably [24]. Similarly, Microsoft’s InnerEye is a computer-assisted image diagnostic chatbot that recognizes cancers and diseases within the eye, but does not directly interact with the user like a chatbot [42]. Even with the rapid advancements of AI in cancer imaging, a major issue is the lack of a gold standard [58].

From the patient’s perspective, various chatbots have been designed for symptom screening and self-diagnosis. The ability for patients to be directed to urgent referral pathways through early warning signs has been a promising market. Decreased wait times in accessing healthcare services have been found to correlate with improved patient outcomes and satisfaction [59-61]. The automated chatbot, Quro, provides pre-synopsis based on symptoms and history to predict user conditions (average precision ~ 0.82) without a form-based data entry system [25]. In addition to diagnosis, Buoy Health assists users in identifying the cause of their illness and provides medical advice [26]. Another chatbot designed by Harshitha et al. uses dialog flow to give an initial analysis of breast cancer symptoms. It has been proved to be 95% accurate in differentiating between normal and cancerous images [27]. Even with the promising results, there are still potential areas for improvement. A study of three mobile-app based chatbot symptom checkers (Babylon, Your.Me, and Ada) indicated that sensitivity remained low at 33% for the detection of head and neck cancer [28]. The number of studies assessing the development, implementation, and effectiveness are still relatively limited compared to the diversity of chatbots currently available. More studies are required to establish efficacy across various conditions and populations. Nonetheless, chatbots for self-diagnosis is an effective way to advise patients as the first point of contact if accuracy and sensitivity requirements can be satisfied.

Early cancer detection can lead to higher survival rates and improved quality of life. Inherited factors are present in 5-10% of cancers, including breast, colorectal, prostate, and rare tumour syndromes [62]. Family history collection is a proven way to easily access the genetic disposition of developing cancer to inform risk-stratified decision making, clinical decisions, and cancer prevention [63]. Web-based chatbot, ItRuns, gathers family history information at the population level to determine the risk of hereditary cancer [29]. We have yet to find a chatbot that incorporates deep learning to process large and complex datasets at a cellular level. Although not able to directly converse with users, DeepTarget [64] and deepMirGene [65] are capable of performing miRNA and target prediction using expression data with higher accuracy compared to non-deep learning models. With the advent of phenotype-genotype predictions, chatbots for genetic screening would greatly benefit from image recognition. New screening biomarkers are also being discovered at a rapid speed, so continual integration and algorithm training are required. These findings align with studies that demonstrate chatbots have the potential to improve user experience, accessibility, and provide accurate data collection [66].

**Treatment**

Chatbots have now been able to provide patients with treatment and medication information after diagnosis, without having to directly contact a physician. Such a system was
proposed by Mathew et al. that identifies the symptoms, predicts the disease using a symptom-
disease dataset, and recommends a suitable treatment [30]. Although this may seem like an
attractive option for patients looking for a fast solution, computers are still prone to errors and
bypassing professional inspection may be an area of concern. Chatbots may also be an effective
resource for patients who want to learn why a certain treatment is necessary. Madhu et al.
proposed an interactive chatbot application that provides a list of available treatments for
various diseases, including cancer. This system also informs the user of the composition and
prescribed use of the medications to help select the best course of action [31]. The diagnosis
and course of treatment for cancer are complex, so a more realistic system would be a chatbot
used to connect users with the appropriate specialists or resources. A text-to-text chatbot by
Divya et al. engages patients about their medical symptoms to provide a personalized diagnosis
and connects the user with the appropriate physician if major diseases are detected [32]. Rarhi
et al. proposed a similar design that provides a diagnosis based on symptoms, measure the
seriousness, and connect users with a physician if needed [33]. In general, these systems may
greatly help individuals in conducting daily check-ups, increase awareness of their health
status, and encourage users to seek medical assistance for early intervention.

Chatbots have also been used by physicians during treatment planning. An example is
IBM’s Watson for Oncology that examines data from records and medical notes to generate an
evidence-based treatment plan for oncologists [34]. Studies have shown that Watson for
Oncology still cannot replace experts at this moment because quite a few cases are not
consistent with experts (~73% concordant) [67, 68]. Nonetheless, this could be an effective
decision-making tool for cancer therapy to standardize treatments. Although not specifically an
oncology application, another chatbot example for clinician’s use is the chatbot Safedrugbot
[69]. This is a chat messaging service for health professionals offering assistance about
appropriate drug use information during breastfeeding. Promising progress has also been
made for using AI in radiotherapy to reduce the workload of radiation staff or identify at-risk
patients by collecting outcomes before and after treatment [70]. An ideal chatbot for healthcare
professionals’ use would be able to accurately detect diseases and provide the proper course of
recommendations, which are functions currently limited by time and budgetary constraints.
Continual algorithm training and updates would be necessary because of the constant
improvements with current standards of care. Further refinements and testing for accuracy to
algorithms are required before clinical implementation [71]. This area holds tremendous
potential as an estimated 50% or more of all cancer patients have used radiotherapy during the
course of their treatment.

Patient Monitoring

Chatbots have been implemented in remote patient monitoring for post-operative care
and follow-ups. The healthcare sector is among the most overwhelmed by those needing
continued support outside hospital settings as the majority of patients newly diagnosed with
cancer are 65 years or older [72]. The integration of this application would improve patients’
quality of life and relieve the burden on healthcare providers through better disease
management, reducing the cost of visits, and allowing timely follow-ups. In terms of cancer
therapy, remote monitoring can support patients by enabling higher dose chemotherapy drug
delivery, reducing secondary hospitalizations, and providing health benefits after surgery [73–
75].

STREAMD, Conversa, and Memora Health are chatbots that function on existing
messaging platforms that provide patients with immediate access to care instructions and
educational information [35]. To ensure patients are adhering to instructions, AiCure uses a
smartphone webcam to coach them in managing their condition. Recently, a chatbot
architecture was proposed for patient support based on microservices to provide personalized eHealth functionalities and data storage [36]. Several studies have supported the application of chatbots for patient monitoring [76]. The semi-automized messaging chatbot, Infinity, was used to assess the health outcomes and healthcare impact of phone-based monitoring for cancer patients 65 years and older. After two years of implementation, there was a 97% satisfactory rate and 87% considered monitoring useful with the most reported benefit due to treatment management and moral support [37]. Similar results were discovered from two studies using Vik, a text-based chatbot that responds to the daily needs and concerns of patients and their relatives with personal insights. A one-year prospective study of 4737 breast cancer patients had a 94% overall satisfaction rate [38]. More in-depth analysis of the 132,970 messages showed that users were more likely to answer multiple choice questions compared to open-ended ones, chatbots improved treatment compliance rate by over 20% (p=0.04), and intimate or sensitive topics were openly discussed. An area of concern is that retention rates drastically decreased to 31% by the end of this study. The other study was a phase three, blind, non-inferiority randomized controlled trial (n=132) to assess the level of patient satisfaction of answers provided by chatbots vs. physicians [39]. Using 12 frequently asked questions about breast cancer, participants were split into two groups to rate the quality of answers from chatbots or physicians. Among breast cancer patients in treatment or remission, chatbots answers were shown to be non-inferior (p<0.001) with a success rate of 69% compared to 64% in physician groups. Concerns about the chatbot’s ability to successfully answer more complex questions or detecting differences between major and minor symptoms still remain to be addressed.

Further refinements and large scale implementation is still required to determine the benefits across different populations and sectors in healthcare [26]. Although overall satisfaction is found to be relatively high, there is still room for improvement by taking into account user feedback tailored to the patient’s changing needs during recovery. In combination with wearable technology and affordable software, chatbots have great potential to impact patient monitoring solutions.

**Patient Support**

The prevalence of cancer is increasing along with the number of cancer survivors partly due to the improved treatment techniques and early detection [77]. These individuals experience added health problems, such as infections, chronic diseases, psychological issues, and sleep disturbances, which often require specific needs not able to be met by many practitioners (ie. medical, psychosocial, informational, and proactive contact) [78]. A number of these individuals require support after hospitalization or treatment periods. Maintaining autonomy and living in a self-sustaining way within their home environment is especially important for older populations [79]. Implementation of chatbots may address some of these concerns, such as reducing the burden on the healthcare system and supporting independent living.

With psychiatric disorders affecting at least 35% of cancer patients, comprehensive cancer care now includes psychosocial support to reduce distress and foster a better quality of life [80]. The first chatbot was designed for individuals with psychological issues [9], but they continue to be used for emotional support and psychiatric counselling with their ability to express sympathy and empathy [81]. Health-based chatbots delivered through mobile applications, such as Woebot, Youper, Wysa, Replika, Unmind, and Shim offer daily emotional support and mental health tracking [26]. A study performed on Woebot, developed based on cognitive behavioural therapy, showed that depressive symptoms were significantly reduced and participants were more receptive than traditional therapies [41]. This agreed with the
Shim results, also using the same type of therapy, which showed that the intervention was highly engaging, improved well-being, and reduced stress [82]. When another chatbot was developed based on the structured association technique counselling method, the user’s motivation was enhanced and stress was reduced [83]. Similarly, a graph-based chatbot has been proposed to identify the mood of users through sentimental analysis and provide human-like responses to comfort patients [84]. Vivobot provides cognitive and behavioural intervention to deliver positive psychology skills and promote well-being. This psychiatric counselling chatbot was effective in engaging users and reduced anxiety for young adults after cancer treatment [40]. The limitation to the studies above was that the majority of participants were young adults, most likely due to the platform the chatbots were available on. Additionally, longer follow-up periods with larger and more diverse sample sizes are needed for future studies. Chatbots used for psychological support hold great potential because individuals are more comfortable disclosing personal information when no judgements are formed, even if users could still discriminate their responses from that of humans' [82, 85].

Workflow Efficiency

Electronic health records have improved data availability, but also increased the complexity of clinical workflow contributing to ineffective treatment plans and uninformed management [86]. A streamlined process using ML techniques would allow clinicians to spend more time with patients by decreasing the time spent on data entry through the ease of documentation, exposing relevant patient information from the chart, automatically authorizing payment, or reducing medical errors [58]. For example, Mandy is a chatbot that assists healthcare staff by automating the patient intake process. Using a combination of data-driven natural language processing with knowledge-driven diagnostics, this chatbot interviews the patient, understands their chief complaints, and submits reports to physicians for further analysis [43]. Similarly, Sense.ly acts as a virtual nurse to assist in monitoring appointments, manage patients’ conditions, and suggest therapies. Another chatbot that reduces the burden on clinicians and decreases wait times is Careskore that tracks vitals and anticipates the need for hospital admissions [42]. Chatbots have also been proposed to autonomize the patient encounters through several advanced eHealth services. In addition to collecting data and providing bookings, Health On-Line Medical Suggestions (HOLMeS) interacts with the patients to support diagnosis, choose the proper treatment pathway, and provide prevention check-ups [44]. Although the use of chatbots in healthcare and cancer therapy has the potential to enhance clinician efficiency, reimbursement codes for practitioners are still lacking before universal implementation. Additionally, studies will be to be conducted to validate the effectiveness of chatbots in streamlining workflow for different healthcare settings. Nonetheless, chatbots hold great potential to complement telemedicine by streamlining medical administration and autonomizing patient encounters.

Health Promotion

Cancer survivors, particularly those who underwent treatment during childhood, are more susceptible to adverse health risks and medical complications. Consequently, promoting a healthy lifestyle early on is imperative to maintain quality of life, reduce mortality, and decrease the risk of secondary cancers [87]. According to the analysis from the web directory, heath promotion chatbots are the most commonly available, but most of them are only available on a single platform. Thus, interoperability on multiple common platforms is essential for adoption by various types of users across different age groups. Additionally, voice and image recognition should also be considered as most are still text-based.

Healthy diets and weight control are key to successful disease management as obesity
playing a significant risk for chronic conditions. Chatbots have been incorporated into health coaching systems to address health behaviour modification. For example, CoachAI and Smart Wireless Interactive Health System (SWITCHeS) track patients’ progress, provides insight to physicians, and suggest suitable activities [45, 46]. Another application is Weight Mentor that provides self-help motivation for weight loss maintenance and allows for open conversation without being affected by emotions [47]. Health Hero, Tasteful Bot, Forksy, and SLOWbot guides users to make informed decisions around food choices to change unhealthy eating habits [48, 49]. The effectiveness of these applications can not be concluded because more rigorous analysis of the development, evaluation, and implementation is required. Nevertheless, chatbots are emerging as a solution for healthy lifestyle promotion through access and human-like communication while maintaining anonymity.

Most would assume cancer survivors would be more inclined to practice health protection behaviours with the extra guidance from health professionals, but results have been surprising. Smoking accounts for at least 30% of all cancer deaths, but up to 50% of survivors continue to smoke [88]. The benefit of using chatbots for smoking cessation across various age groups has been highlighted in numerous studies showing improved motivation, accessibility, and adherence to treatment which have led to increased smoking abstinence [89-91]. Cognitive behaviour therapy-based chatbot, SMAG, supporting users over Facebook social network resulted in 10% high cessation rate compared to control groups [50]. Motivational interview-based chatbots have been proposed with promising results, where a significant number of subjects showed an increase in their confidence and readiness to quit smoking after one week [92]. No studies have been found to access the effectiveness of chatbots for smoking cessation in terms of ethnic, racial, geographic, or socioeconomic status differences. Creating chatbots with pre-specified answers is simple, but the problem becomes more complex when answers are open. Bella, one of the most advanced text-based chatbots on the market advertised as a coach for adults, gets stuck when responses are not prompted [51]. Therefore, reacting to unexpected responses is still an area in progress. Given all the uncertainties, chatbots hold potential for those looking to quit smoking because they prove to be more acceptable for users when dealing with stigmatized health issues compared to general practitioners [7].

Discussion

Challenges and Limitations

Advances in AI and ML have moved forward at impressive rates and revealed the potential of chatbots in healthcare and clinical settings. AI technology outcompetes humans in terms of image recognition, risk stratification, improved processing, and 24/7 assistance with data and analysis. However, there is no machine substitute for higher-level interaction, critical thinking, and ambiguity [93]. Chatbots create added complexity that must be identified, addressed, and mitigated before their universal adoption in healthcare.

Hesitancy from physicians and poor adoption by patients is a major barrier to overcome, which could be explained by many of the factors discussed in this section. A cross-sectional web-based survey of 100 practicing physicians gathered the perceptions of chatbots in healthcare [6]. Although a wide variety of beneficial aspects were reported (i.e. management of health and administration), an equal amount of concerns were present. Over 70% of physicians believed that chatbots cannot effectively care for all of the patients’ needs, cannot display human emotion, cannot provide detailed treatment plans, and poses a risk if patients self-diagnose or do not fully comprehend their diagnosis. If the limitations of chatbots are better
understood and mitigated, the fears of adopting this technology into healthcare may slowly subside. We end the discussion by exploring challenges and questions for healthcare professionals, patients, and policymakers.

Moral and Ethical Constraints

The use of chatbots in healthcare presents a novel set of moral and ethical challenges that must be addressed for the public to fully embrace this technology. Issues to consider are privacy or confidentiality, informed consent, and fairness. Each one of these concerns will be addressed below. Although efforts have been made to address these concerns, current guidelines and policies are still far behind the rapid technological advances [94].

Healthcare data is highly sensitive due to the risk of stigmatization and discrimination if the information is wrongfully disclosed. The ability for chatbots to ensure privacy is especially important as vast amounts of personal and medical information are often collected without users being aware, including voice recognition and geographical tracking. The public's lack of confidence is not surprising given the increased frequency and magnitude of high-profile security breaches and inappropriate use of data [95]. Unlike financial data that becomes obsolete after being stolen, medical data are particularly valuable because they are not perishable. Privacy threats may break the trust that is essential to the therapeutic physician-patient relationship and inhibits open communication of relevant clinical information for proper diagnosis and treatment [96].

Chatbots experience the “Black Box” problem, similar to many computing systems programmed using ML that are trained on massive data sets to produce multiple layers of connections. Although they are capable of solving complex problems unimaginable by humans, these systems remain highly opaque and the resulting solutions may be unintuitive. This means that the systems’ behaviour is hard to explain by merely looking inside and understanding exactly how they are programmed is near impossible. For both users and developers, transparency becomes an issue because they aren’t able to fully understand the solution or intervene to predictably change the chatbot’s behaviour [97]. With the novelty and complexity of chatbots, obtaining valid informed consent where patients can make their own health-related risk and benefit assessments becomes problematic [98]. Without sufficient transparency, deciding how certain decisions were made or how errors may occur reduces the reliability of the diagnostic process. The “Black Box” problem also poses a concern to patient autonomy by potentially undermining the shared decision-making between physicians and patients [99]. The chatbot’s personalized suggestions are based on algorithms and refined based on the user’s past responses. The removal of options may slowly reduce the patient’s awareness of alternatives and interfere with free choice [100].

Lastly, the issue of fairness arises with algorithm bias when data used to train and test chatbots do not accurately reflect the people they represent [101]. As the AI field lacks diversity, the bias at the level of the algorithm and modelling choices may be overlooked by developers [102]. In a study using two cases, differences in prediction accuracy were shown concerning gender and insurance type for ICU mortality and psychiatric readmissions [103]. On a larger scale, this may exacerbate barriers to healthcare for minorities or underprivileged individuals leading to worse health outcomes. Identifying the source of algorithm bias is crucial to address healthcare disparities between various demographic groups and improve data collection.

Chances for Errors

Although studies have shown that AI technologies make fewer mistakes compared to humans in terms of diagnosis and decision making, they still bear inherent risks for medical
errors [104]. The interpretation of speech remains prone to errors due to the complexity of background information, accuracy of linguistic unit segmentation, variability in acoustic channels, and linguistic ambiguity with homophones or semantic expressions. Chatbots are unable to efficiently cope with these errors because of the lack of common sense and inability to properly model real-world knowledge [105]. Another factor that contributes to errors and inaccurate predictions is the large noisy data sets used to train modern models because large quantities of high quality, representative data are often unavailable [58]. Aside from the concern of accuracy and validity, addressing clinical utility and effectiveness of improving patients’ quality of life is just as important. With the increased use of diagnostic chatbots, the risk of over-confidence and overtreatment may cause more harm than benefit [99]. There still holds clear potential for improved decision-making as diagnostic deep learning algorithms were found to be equivalent to healthcare professionals in classifying diseases in terms of accuracy [106]. These issues presented above all raise the question of who is legally liable for medical errors. Avoiding responsibility becomes easier when numerous individuals are involved at multiple stages from development to clinical applications [107]. Although the law has been lagging and litigation is still a grey area, determining legal liability becomes increasingly pressing with chatbots becoming more accessible in healthcare.

**Regulatory Considerations**

Regulatory standards have been developed to accommodate for the rapid modifications along with ensuring the safety and effectiveness of AI technology, including chatbots. The US Food and Drug Administration (FDA) has recognized the distinctiveness of chatbots compared to traditional medical devices by defining the software within the medical device category and outlined its approach through the Digital Health Innovation Action Plan [108]. With the growing number of AI algorithms approved by FDA, they opened public consultation for setting performance targets, monitoring performance, and reviewing when performance strays from pre-set parameters [102]. American Medical Association (AMA) has also adopted the Augmented Intelligence in Health Care policy for the appropriate integration of AI into healthcare by emphasizing the design approach and enhancement of human intelligence [109]. One area of concern is that chatbots are not covered under the Health Insurance Portability and Accountability Act (HIPAA), so users’ data may be unknowingly sold, traded, and marketed by companies [110]. On the other hand, over-regulation may diminish the value of chatbots and decrease the freedom for innovators. Consequently, balancing these opposing aspects is essential to promote the benefits and reduce the harms to the healthcare system and society.
Future Directions

Chatbots’ robustness of integrating and learning from large clinical data sets along with its ability to seamlessly communicate with users contributes to its widespread integration in various healthcare applications. Given the current status and challenges of cancer care, chatbots will likely be a key player in this field’s continual improvement. More specifically, they hold promise in addressing the triple aim of healthcare by improving the quality of care, bettering the health of populations, and reducing the burden or cost of our healthcare system. Beyond cancer care, there are increasing numbers of creative ways chatbots could be applicable in healthcare. During the COVID-19 pandemic, chatbots have already been deployed to share information, suggest behaviour, and offer emotional support. They have the potential to prevent misinformation, detect symptoms, and lessen the mental health burden during global pandemics [111]. On a global health level, chatbots have emerged as a socially responsible technology to provide equal access to quality healthcare and break down the barriers between the rich and poor [112]. To further advance medicine and knowledge, the use of chatbots in education for learning and assessments is crucial to providing objective feedback, personalized content, and cost-effective evaluations [113]. For example, the development of the Einstein application as a virtual physics teacher enables interactive learning and evaluations, but is still far from being perfect [114]. Given chatbots’ diverse applications in numerous aspects of healthcare, further research and interdisciplinary collaboration to advance this technology could revolutionize the practice of medicine.

Based on the discussion above, the following features are general directions of future suggestions for improvements in chatbots within cancer care in no particular order of importance:

- Cancer patients may feel vulnerable or fear discrimination from employers or society [115]. Security of sensitive information must be held to the highest standards, especially when personal health information is shared between providers and hospital systems.

- An increasing number of patients are bringing internet-based information to consultations that are not critically assessed for trustworthiness or credibility. If used correctly, the additional health information could enhance understanding, improve the ability to manage their conditions, and increase confidence during interaction with physicians [116]. Unfortunately, this is often not the case and most patients are not adequately informed about the proper screening of information. Ways to address this challenge is to promote awareness and develop patient management guidelines. Chatbots also have the potential to become a key player in their ability to screen for credible information. They could help vulnerable individuals critically navigate online cancer information, especially for the older or more chronic populations that tend to be less technologically adept.

- Current applications of chatbots as computerized decision support systems in diagnosis and treatment are relatively limited. The targeted audience for most have been for patients’ use and few are designed to aid physicians at the point of care. Medical Sieve and Watson for Oncology are the only chatbots found in our search designed specifically for clinicians. There are far more AI tools on the market to help with clinical decision-making without the ability to interact with users [117]. With the rapid data collection from electronic health records, real-time predictions, and links to clinical recommendations, adding chatbot functionalities to current decision aids will only
improve upon patient-centered care and streamline workflow for clinicians.

- More concrete evidence of high quality and accuracy across a broad range of conditions and populations. This entails more representative training data reflecting racial biases and developing peer-reviewed algorithms to reduce the “Black Box” problem.

- Integration into healthcare system, particularly with telemedicine, for seamless delivery from beginning to end. This does not mean replacing in-person care, but rather complementing healthcare workflow to ensure patients receive continuity and coordination of care.

- Reimbursement of chatbot services to physicians who decide to implement this technology to their practice will likely increase adoption rates. Organizations and health providers will likely profit since chatbots allow for a more efficient and reduce cost of delivery.

- Continual training of chatbots as new knowledge is uncovered, such as symptom patterns or standard of care.

- Since the Vik study found that users were more likely to respond to multiple choice questions over open-ended ones [38], chatbot developers should move towards the choice with higher response rates. Studies, survey, and focus groups should continue to be conducted to determine the best ways to converse with users.

- Universal adoption of various technical features: training with additional languages, image recognition, voice recognition, user feedback to improve services according to needs, access on multiple common platforms, and reacting to unexpected responses.

The ability to accurately measure performance is critical for the continual feedback and improvement of chatbots, especially the high standards and vulnerable individuals served in healthcare. Given that the introduction of chatbots to cancer care is relatively recent, rigorous evidence-based research is lacking. Standardized indicators of success between users and chatbots need to be implemented by regulatory agencies before adoption. Once the primary purpose is defined, common quality indicators to consider are the success rate of a given action, non-response rate, comprehension quality, response accuracy, retention/adoption rates, engagement, and satisfaction level. The ultimate goal is to assess whether chatbots positively impacted and addresses the three aims of healthcare. Regular quality checks are especially critical for chatbots acting as a decision aid because they could have a major impact on patients’ health outcomes.

**Review Limitations**

The systematic literature review and chatbot database search includes a few limitations. The literature review and chatbot search were all conducted by a single reviewer, which could potentially have introduced bias and limited findings. Additionally, our review explored a broad range of healthcare topics and some areas could have been elaborated upon and explored more deeply. Furthermore, only a limited number of studies were included for each subtopic of chatbot for oncology applications due to the scarcity of studies addressing this topic. Future studies should consider refining the search strategy to identify other potentially relevant sources that may have been overlooked and assign multiple reviews to limit individual bias.
Conclusion

As illustrated in this review, these chatbots’ potential in cancer diagnostics and treatment, patient monitoring and support, clinical workflow efficiency, and health promotion have yet to be fully explored. Numerous risks and challenges will continue to arise that require careful navigation with the rapid advancements of chatbots. Consequently, weighing the gains versus threats with a critical eye is imperative. Even after laying down the proper foundations for using chatbots safely and effectively, the human element in the practice of medicine is irreplaceable and will always be present. Healthcare professionals have the responsibility to understand both the benefits and risks associated with chatbots, and in turn educate their patients.

Acknowledgements

This work is supported by a Canadian Institutes of Health Research Planning and Dissemination Grant – Institute Community Support, under the grant number: CIHR PCS - 168296.

Conflicts of Interest

The authors declare no conflict of interests for this article. The research was conducted in absence of any commercial or financial relationships.

Abbreviations

AI: artificial intelligence
ML: machine learning
AIML: Artificial Intelligence Markup Language
FDA: Food and Drug Administration
AMA: American Medical Association
HIPAA: Health Insurance Portability and Accountability Act

References

1. Kersting K. Machine Learning and Artificial Intelligence: Two Fellow Travelers on the Quest for Intelligent Behavior in Machines. Front Big Data. 2018;1(November):1–4.
2. Sathya D., Sudha V., Jagadeesan D. Application of Machine Learning Techniques in Healthcare. In 2019. p. 289–304.
3. Dahiya M. A Tool of Conversation: Chatbot. Int J Comput Sci Eng [Internet]. 2017; (55):158–61. Available from: http://www.ijcseonline.org/pub_paper/27-IJCSE-02149.pdf
4. Manning MS, Weninger C. Analysing Discourse: Textual Analysis for Social Research. Vol. 15, Linguistics and Education. 2004. p. 303–6.
5. Laranjo L, Dunn AG, Tong HL, Kocaballi AB, Chen J, Bashir R, et al. Conversational agents in healthcare: A systematic review. J Am Med Informatics Assoc. 2018;25(9):1248–58.
6. Palanica A, Flaschner P, Thommandram A, Li M, Fossat Y. Physicians’ perceptions of chatbots in health care: Cross-sectional web-based survey. J Med Internet Res.
7. Miles O. Acceptability of chatbot versus General Practitioner consultations for healthcare conditions varying in terms of perceived stigma and severity (Preprint). Qeios. 2020; (2004):2016–7.
8. Turing A. MIND. Mind. 1950;59:433–60.
9. Weizenbaum J. ALIZA-a computer program for the study of natural language.pdf. 1966. p. 36–45.
10. Colby KM, Weber S, Hilf FD. Artificial Paranoia. Artif Intell. 1971;2(1):1–25.
11. Shawar BA, Atwell E. ALICE chatbot: Trials and outputs. Comput y Sist. 2015;19(4):625–32.
12. Shriver B, Smith B. The Anatomy of a. 2014;14(2):49–51.
13. Molnar G, Szuts Z. The Role of Chatbots in Formal Education. SISY 2018 - IEEE 16th Int Symp Intell Syst Informatics, Proc. 2018;197–201.
14. Nimavat K, Champaneria T. Chatbots: An Overview Types, Architecture, Tools and Future Possibilities. Int J Sci Res Dev. 2017;5(7):1019–26.
15. Adamopoulou E, Moussiaides L. An Overview of Chatbot Technology. In: IFIP Advances in Information and Communication Technology. Springer; 2020. p. 373–83.
16. Hien HT, Cuong PN, Nam LNH, Nhung HLTK, Thang LD. Intelligent assistants in higher-education environments: The FIT-EBOt, a chatbot for administrative and learning support. ACM Int Conf Proceeding Ser. 2018;69–76.
17. Pavel Kucherbaev Alessandro Bozzon G-JH. Human Aided Bots. IEEE Internet Comput. 2018;
18. Siegel RL, Miller KD, Jemal A. Cancer statistics, 2020. CA Cancer J Clin. 2020;70(1):7–30.
19. Pizzoli SFM, Renzi C, Arnaboldi P, Russell-Edu W, Pravettoni G. From life-threatening to chronic disease: Is this the case of cancers? A systematic review. Cogent Psychol [Internet]. 2019;6(1):1–17. Available from: https://doi.org/10.1080/23311908.2019.1577593
20. Wolfe A. Institute of Medicine Report: Crossing the Quality Chasm: A New Health Care System for the 21st Century. Science (80- ). 1971;172(3984):635.
21. Berwick DM, Nolan TW, Whittington J. The triple aim: Care, health, and cost. Health Aff. 2008;27(3):759–69.
22. Bode A, Zigang D. Cancer Prevention Research–Then and Now Ann. Bone [Internet]. 2011;23(1):1–7. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3624763/pdf/nihms412728.pdf
23. Tran G, Zafar SY. Price of Cancer Care and Its Tax on Quality of Life. J Oncol Pract. 2018;14(2):69–71.
24. T. Syeda-Mahmood, E. Walach, D. Beymer, F. Gilboa-Solomon, M. Moradi, P. Kisilev, D. Kakrania, C. Compas, H. Wang, R. Negahdar, Y. Cao, T. Baldwin, Y. Guo, Y. Gur, D. Rajan, A. Zlotnick, S. Rabinovich-Cohen, R. Ben-Ari, Amit Guy, P. Prasanna, J. Morey, O. SH. Medical sieve : a cognitive assistant for radiologists and cardiologists. 2016;2020.
25. Ghosh S, Bhatia S, Bhatia A. Quro : Facilitating ser yptom heck sing aersonalised hatbot riented iialogue ystem. 2018;0.
26. Jeddi Z, Bohr A. Remote patient monitoring using artificial intelligence. Artificial Intelligence in Healthcare. 2020. 203–234 p.
27. Harshitha, Chaitanya V, Killedar SM, Revankar D, Pushpa MS. Recognition and Prediction of Breast Cancer using Supervised Diagnosis. 2019 4th IEEE Int Conf Recent Trends Electron Information, Commun Technol RTEICT 2019 - Proc. 2019;1436–41.
28. Fleming J, Jeannon JP. Head and neck cancer in the digital age: an evaluation of mobile health applications. BMJ Innov. 2020;6(1):13–7.
29. Welch BM, Allen CG, Ritchie JB, Morrison H, Hughes-Halbert C, Schiffman JD. Using a Chatbot to Assess Hereditary Cancer Risk. JCO Clin Cancer Informatics. 2020;(4):787–93.
30. Mathew RB, Varghese S, Joy SE, Alex SS. Chatbot for disease prediction and treatment recommendation using machine learning. Proc Int Conf Trends Electron Informatics, ICOEI 2019. 2019;(Iccoi):851–6.
31. Madhu D, Jain CJN, Sebastain E, Shaji S, Ajayakumar A. A novel approach for medical assistance using trained chatbot. Proc Int Conf Inven Commun Comput Technol ICICICT 2017. 2017;(Icicct):243–6.
32. Divya S, Indumathi V, Ishwarya S, Priyasankari M, S KD. A Self-Diagnosis Medical Chatbot Using Artificial Intelligence. 2018;3(1):1–7.
33. Rahi K, Bhattacharya A, Mishra A, Mandal K. Automated Medical Chatbot. SSRN Electron J. 2018;0–2.
34. Zauderer MG, Gucalp A, Epstein AS, Seidman AD, Caroline A, Granovsky S, et al. Piloting IBM Watson Oncology within Memorial Sloan Kettering’s regional network. J Clin Oncol [Internet]. 2014;32(15 SUPPL. 1):no pagination. Available from: http://meeting.ascopubs.org/cgi/content/abstract/32/15_suppl/e17653?sid=ad2b6d30-ec22-453b-8a8c-67c23fbd7f85%0Ahttp://ovidsp.ovid.com/ovidweb.cgi? T=JS&PAGE=reference&DEd=emed12&NEWS=N&AN=71523844
35. Campbell K, Louie P, Levine B, Gililland J. Using Patient Engagement Platforms in the Postoperative Management of Patients. Curr Rev Musculoskelet Med. 2020;13(4):479–84.
36. Roca S, Sancho J, García J, Alesanco Á. Microservice chatbot architecture for chronic patient support. J Biomed Inform. 2020;102(September).
37. Piau A, Crissey R, Brechemier D, Balardy L, Nourhashemi F. A smartphone Chatbot application to optimize monitoring of older patients with cancer. Int J Med Inform. 2019;128(February):18–23.
38. Chaix B, Bibault JE, Pienkowski A, Delamon G, Guillemassé A, Nectoux P, et al. When chatbots meet patients: One-year prospective study of conversations between patients with breast cancer and a chatbot. J Med Internet Res. 2019;21(5):1–7.
39. Bibault JE, Chaix B, Guillemassé A, Cousin S, Escande A, Perrin M, et al. A chatbot versus physicians to provide information for patients with breast cancer: Blind, randomized controlled noninferiority trial. J Med Internet Res. 2019;21(11):1–7.
40. Greer S, Ramo D, Chang YJ, Fu M, Moskowitz J, Haritatos J. Use of the chatbot “vivibot” to deliver positive psychology skills and promote well-being among young people after cancer treatment: Randomized controlled feasibility trial. JMIR mHealth uHealth. 2019;7(10):1–13.
41. Fitzpatrick KK, Darcy A, Vierhile M. Delivering Cognitive Behavior Therapy to Young Adults With Symptoms of Depression and Anxiety Using a Fully Automated Conversational Agent (Woebot): A Randomized Controlled Trial. JMIR Ment Heal. 2017;4(2):e19.
42. Rayan RA. Artificial Intelligence Perspective on Healthcare.
43. Ni L, Lu C, Liu N, Liu J. MANDY: Towards a smart primary care chatbot application. In: Communications in Computer and Information Science. Springer Verlag; 2017. p. 38–52.
44. Amato F, Marrone S, Moscato V, Piantadosi G, Picariello A, Sansone C. Chatbots meet eHealth: Automating Healthcare. CEUR Workshop Proc. 2017;
45. Fadhil A. Text-based Chatbot Assisted Health Coaching System: Preliminary Evaluation & Results. 2019;1–9.
46. Huang CY, Yang MC, Chen YJ, Wu ML, Chen KW. A Chatbot-supported Smart Wireless Interactive Healthcare System for Weight Control and Health Promotion. IEEE Int Conf
Holmes SL, Moorhead AS, Bond RB, Zheng H, Coates V, McTear M. WeightMentor: A New Automated Chatbot for Weight Loss Maintenance. 2018;1–5.

Fadhil A. Can a Chatbot Determine My Diet?: Addressing Challenges of Chatbot Application for Meal Recommendation. 2018; Available from: http://arxiv.org/abs/1802.09100

Gabrielli S, Marie K, Corte C Della. SLOWBot (chatbot) lifestyle assistant. ACM Int Conf Proceeding Ser. 2018;367–70.

Calvaresi D, Calbimonte JP, Dubosson F, Najjar A, Schumacher M. Social network chatbots for smoking cessation: Agent and multi-agent frameworks. Proc - 2019 IEEE/WIC/ACM Int Conf Web Intell WI 2019. 2019;286–92.

Simon P, Krishnan-Sarin S, Huang T-H “Kenneth.” On Using Chatbots to Promote Smoking Cessation Among Adolescents of Low Socioeconomic Status. 2019; Available from: http://arxiv.org/abs/1910.08814

Savage BN. Savage-2020-How-ai-is-improving-cancer-diagnost. 2020;

Hollon TC, Pandian B, Adapa AR, Urias E, Save A V, Khalsa SSS, et al. Near real-time intraoperative brain tumor diagnosis using stimulated Raman histology and deep neural networks. Nat Med. 2020;26(1):52–8.

Bejnordi BE, Veta M, Van Diest PJ, Van Ginneken B, Karssemeijer N, Litjens G, et al. Diagnostic assessment of deep learning algorithms for detection of lymph node metastases in women with breast cancer. JAMA - J Am Med Assoc. 2017;318(22):2199–210.

Rees, C.; Koo S. Artificial intelligence — upping the game in gastrointestinal endoscopy? J Feline Med Surg. 2019;21(11):1064–6.

Marchetti MA, Codella NCF, Dusza SW, Gutman DA, Helba B, Kalloo A, et al. Results of the 2016 International Skin Imaging Collaboration International Symposium on Biomedical Imaging challenge: Comparison of the accuracy of computer algorithms to dermatologists for the diagnosis of melanoma from dermoscopic images. J Am Acad Dermatol. 2018;78(2):270-277.e1.

Nichols JA, Herbert Chan HW, Baker MAB. Machine learning: applications of artificial intelligence to imaging and diagnosis. Vol. 11, Biophysical Reviews. Springer Verlag; 2019. p. 111–8.

Rajkomar A, Dean J, Kohane I. Machine learning in medicine. N Engl J Med. 2019;380(14):1347–58.

Song H, Fang F, Valdimarsdóttir U, Lu D, Andersson TML, Hultman C, et al. Waiting time for cancer treatment and mental health among patients with newly diagnosed esophageal or gastric cancer: A nationwide cohort study. BMC Cancer. 2017;17(1):1–9.

Martinez DA, Zhang H, Bastias M, Feijoo F, Hinson J, Martinez R, et al. Prolonged wait time is associated with increased mortality for Chilean waiting list patients with non-prioritized conditions. BMC Public Health. 2019;19(1):1–11.

Mathews M, Ryan D, Gadag V, West R. Patient satisfaction with wait-times for breast cancer surgery in Newfoundland and Labrador Healthc Policy. 2016;11(3):42–53.

Gopie JP, Vasen HFA, Tibben A. Surveillance for hereditary cancer: Does the benefit outweigh the psychological burden?-A systematic review. Crit Rev Oncol Hematol. 2012;83(3):329–40.

Pyeritz RE. The family history: The first genetic test, and still useful after all those years? Genet Med. 2012;14(1):3–9.

Lee B, Park S, Baek J, Yoon S. DeepTarget: End-to-end learning framework for MicroRNA target prediction using deep recurrent neural networks. ACM-BCB 2016 - 7th ACM Conf
65. Park S, Min S, Choi H, Yoon S. deepMiRGene: Deep Neural Network based Precursor microRNA Prediction. 2016; Available from: http://arxiv.org/abs/1605.00017
66. Welch BM, Wiley K, Pfieger L, Achiangia R, Baker K, Hughes-halbert C, et al. Review and comparison of electronic patient-facing family health history tools. 2019;27(2):381–91.
67. Liu C, Liu X, Wu F, Xie M, Feng Y, Hu C. Using artificial intelligence (watson for oncology) for treatment recommendations amongst Chinese patients with lung cancer: Feasibility study. J Med Internet Res. 2018;20(9):30257820.
68. Zou FW, Tang YF, Liu CY, Ma JA, Hu CH. Concordance Study Between IBM Watson for Oncology and Real Clinical Practice for Cervical Cancer Patients in China: A Retrospective Analysis. Front Genet. 2020;11(March):1–8.
69. Meskó B, Hetényi G, Gyorffy Z. Will artificial intelligence solve the human resource crisis in healthcare? BMC Health Serv Res. 2018;18(1):1–4.
70. Bibault JE, Chaix B, Nectoux P, Pienkowski A, Guillemasse A, Brouard B. Healthcare ex Machina: Are conversational agents ready for prime time in oncology? Vol. 16, Clinical and Translational Radiation Oncology. Elsevier Ireland Ltd; 2019. p. 55–9.
71. Siddique S, Chow JCL. Artificial intelligence in radiotherapy. Vol. 25, Reports of Practical Oncology and Radiotherapy. Urban and Partner; 2020. p. 656–66.
72. Schrijvers D. Lung cancer in the elderly. ESMO Handb Cancer Sr Patient. 2010;117:98–108.
73. Weaver A, Young AM, Rowntree J, Townsend N, Pearson S, Smith J, et al. Application of mobile phone technology for managing chemotherapy-associated side-effects. Ann Oncol [Internet]. 2007;18(11):1887–92. Available from: https://doi.org/10.1093/annonc/mdm354
74. Compaci G, Ysebaert L, Obéric L, Derumeaux H, Laurent G. Effectiveness of telephone support during chemotherapy in patients with diffuse large B cell lymphoma: The Ambulatory Medical Assistance (AMA) experience. Int J Nurs Stud. 2011;48(8):926–32.
75. van der Meij E, Anema JR, Leclercq WKG, Bongers MY, Consten ECJ, Schraffordt Koops SE, et al. Personalised perioperative care by e-health after intermediate-grade abdominal surgery: a multicentre, single-blind, randomised, placebo-controlled trial. Lancet [Internet]. 2018;392(10141):51–9. Available from: http://dx.doi.org/10.1016/S0140-6736(18)31113-9
76. Peyrou B, Vignaux J-J, André A. Artificial Intelligence and Health Care. In 2019. p. 29–40.
77. Moor JS De, Mariotto AB, Parry C, Alfano CM, Padgett L, Kent EE, et al. Cancer Survivors in the United States: Prevalence across the Survivorship Trajectory and Implications for Care. 2014;1–17.
78. Hoekstra RA, Heins MJ, Korevaar JC. Health care needs of cancer survivors in general practice: A systematic review. BMC Fam Pract. 2014;15(1):1–6.
79. Atherton J. Autonomy and Quality of Life for Elderly Patients. 2011;13(7):494–8. Available from: http://journalofethics.ama-assn.org/2012/09/pdf/stas1-1209.pdf
80. Caruso R, Breitbart W. Mental health care in oncology. Contemporary perspective on the psychosocial burden of cancer and evidence-based interventions. Epidemiol Psychiatr Sci. 2020;29.
81. Liu B, Sundar SS. Should Machines Express Sympathy and Empathy? Experiments with a Health Advice Chatbot. Cyberpsychology, Behav Soc Netw. 2018;21(10):625–36.
82. Ly KH, Ly AM, Andersson G. A fully automated conversational agent for promoting mental well-being: A pilot RCT using mixed methods. Internet Interv. 2017;10(August):39–46.
83. Kamita T, Ito T, Matsumoto A, Munakata T, Inoue T. A Chatbot System for Mental Healthcare Based on SAT Counseling Method. Mob Inf Syst. 2019;
84. Belfin R V., Shobana AJ, Manilal M, Mathew AA, Babu B. A Graph Based Chatbot for Cancer Patients. 2019 5th Int Conf Adv Comput Commun Syst ICACCS 2019. 2019;717–21.
85. Lucas GM, Gratch J, King A, Morency LP. It's only a computer: Virtual humans increase willingness to disclose. Comput Human Behav. 2014;37:94–100.
86. Chen Y, Xie W, Gunter CA, Liebovitz D, Mehrotra S, Zhang H, et al. Inferring Clinical Workflow Efficiency via Electronic Medical Record Utilization. AMIA . Annu Symp proceedings AMIA Symp. 2015;2015:416–25.
87. Tyc VL, Hudson MM, Hinds P. Health promotion interventions for adolescent cancer survivors. Cogn Behav Pract. 1999;6(2):128–36.
88. Jassem J. Tobacco smoking after diagnosis of cancer: Clinical aspects. Transl Lung Cancer Res. 2019;8(Suppl 1):S50–8.
89. Perski O, Crane D, Beard E, Brown J. Does the addition of a supportive chatbot promote user engagement with a smoking cessation app? An experimental study. Digit Heal. 2019;5:1–13.
90. Wang MP, Luk TT, Wu Y, Li WH, Cheung DY, Kwong AC, et al. Chat-based instant messaging support integrated with brief interventions for smoking cessation: a community-based, pragmatic, cluster-randomised controlled trial. Lancet Digit Heal [Internet]. 2019;1(4):e183–92. Available from: http://dx.doi.org/10.1016/S2589-7500(19)30082-2
91. Avila-Tomas JF, Olano-Espinosa E, Minué-Lorenzo C, Martinez-Suberbiola FJ, Matilla-Pardo B, Serrano-Serrano ME, et al. Effectiveness of a chat-bot for the adult population to quit smoking: protocol of a pragmatic clinical trial in primary care (Dejal@) | BMC Medical Informatics and Decision Making | Full Text. BMC Med Inform Decis Mak [Internet]. 2019;19(1):249. Available from: https://bmcmedinformdecismak.biomedcentral.com/articles/10.1186/s12911-019-0972-z
92. Mehrizi-sani A. Motivating Smokers to Quit Through a Computer-Based Conversational System. 2011;196.
93. Krittanawong C. The rise of artificial intelligence and the uncertain future for physicians. 2017;48:13–4. Available from: http://arxiv.org/abs/1703.02442
94. Rigby MJ. Ethical dimensions of using artificial intelligence in health care. AMA J Ethics. 2019;21(2):121–4.
95. Seh AH, Zarour M, Alenezi M, Sarkar AK, Agrawal A, Kumar R, et al. Healthcare Data Breaches: Insights and Implications. Healthcare. 2020;8(2):133.
96. Luxton DD. Recommendations for the ethical use and design of artificial intelligent care providers. Artif Intell Med. 2014;62(1):1–10.
97. Zednik C. Solving the Black Box Problem: A Normative Framework for Explainable Artificial Intelligence. Philos Technol. 2019;
98. Astromské K, Peičius E, Astromskis P. Ethical and legal challenges of informed consent applying artificial intelligence in medical diagnostic consultations. AI Soc. 2020; (0123456789).
99. Grote T, Berens P. On the ethics of algorithmic decision-making in healthcare. J Med Ethics. 2020;46(3):205–11.
100. Law L, Online R. Selected Issues Concerning the Ethical Use of Big Data Health Analytics. 2016;72(3).
101. Zou J, Schiebinger L. AI can be sexist and racist — it’s time to make it fair. Nature. 2018;559(7714):324–6.
102. Fenech ME. Maximising the Opportunities of Artificial Intelligence for People Living With Cancer. Clin Oncol [Internet]. 2020;32(2):e80–5. Available from:
103. Celie K-B, Prager K, Chaet D, Johnston C, Yarmolinsky R. Can AI Help Reduce Disparities in General Medical and Mental Health Care? Clin Ethics. 2016;18(5):473–563.
104. Bächle TC. On the ethical challenges of innovation in digital health. :47–55.
105. Niculescu AI, Banchs RE. Strategies to cope with errors in human-machine spoken interactions: using chatbots as back-off mechanism for task-oriented dialogues. Errors by Humans Mach multimedia, multimodal Multiling data Process. 2015;(January).
106. Liu X, Faes L, Kale AU, Wagner SK, Fu DJ, Bruynseels A, et al. A comparison of deep learning performance against health-care professionals in detecting diseases from medical imaging: a systematic review and meta-analysis. Lancet Digit Heal [Internet]. 2019;1(6):e271–97. Available from: http://dx.doi.org/10.1016/S2589-7500(19)30123-2
107. Thompson DF. Moral Responsibility of Public Officials: The Problem of Many Hands. Am Polit Sci Rev [Internet]. 1980 Dec 1 [cited 2020 Nov 4];74(4):905–16. Available from: https://www.cambridge.org/core/product/identifier/S0003055400169515/type/journal_article
108. He J, Baxter SL, Xu J, Xu J, Zhou X, Jolla L, et al. The practical implementation of artificial intelligence technologies in medicine. 2020;25(1):30–6.
109. Crigger E, Khoury C. Number 2: E188-191 MEDICINE AND SOCIETY Making Policy on Augmented Intelligence in Health Care. 2019;21(2):188–91. Available from: www.amajournalofethics.org
110. Vaidyam AN, Wisniewski H, Halamka JD, Kashavan MS, Torous JB. Chatbots and Conversational Agents in Mental Health: A Review of the Psychiatric Landscape. Can J Psychiatry. 2019;64(7):456–64.
111. Miner AS, Laranjo L, Kocaballi AB. Chatbots in the fight against the COVID-19 pandemic. Vol. 3, npj Digital Medicine. Nature Research; 2020.
112. Hosny A, Aerts HJWL. Artificial intelligence for global health. Vol. 366, Science. American Association for the Advancement of Science; 2019. p. 955–6.
113. Garg T. Artificial Intelligence in Medical Education. Am J Med [Internet]. 2020;133(2):e68. Available from: https://doi.org/10.1016/j.amjmed.2019.08.017
114. Anwarulloh TP, Agustia RD, Bandung JD. DEVELOPMENT OF THE CHATBOT EINSTEIN APPLICATION AS A VIRTUAL TEACHER OF PHYSICAL LEARNING IN THE HOUSE Teknik Informatika – Universitas Komputer Indonesia. 2017;
115. Ehrmann-Feldman D, Spitzer WO, Del Greco L, Desmeules L. Perceived discrimination against cured cancer patients in the work force. Can Med Assoc J. 1987;136(7):719–23.
116. Ahmad F, Hudak PL, Bercovitz K, Hollenberg E, Levinson W. Are physicians ready for patients with internet-based health information? J Med Internet Res. 2006;8(3).
117. Clauser SB, Wagner EH, Aiello Bowles EJ, Tuzzio L, Greene SM. Improving modern cancer care through information technology. Am J Prev Med. 2011;40(5 SUPPL. 2):1–16.
Supplementary Files
Figures
Search and screening for healthcare chatbots. Applications using more than one platform are included.
Schematic of general chatbot architecture.