



Digital technologies in cancer care: a review from the clinician's perspective

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Physicians are increasingly utilizing digital health technologies (DHT) such as smartphone applications, network-enabled wearable devices, web-based communication platforms, videoconferencing, chatbots, artificial intelligence and virtual reality to improve access to, and quality of, care. DHT aid in cancer screening, patient education, shared decision-making, promotion of positive health habits, symptom monitoring and intervention, patient-provider communication, provision of psychological support and delivery of effective survivorship care. This narrative review outlines how physicians may utilize digital health to improve or augment their delivery of cancer care. For the full potential of DHT to be realized, experts must develop appropriate solutions to issues surrounding the regulation, liability, quality, security, equity and reimbursement of DHT.

Tweetable abstract: Digital health technology augments the full spectrum of cancer care and can promote personalized medicine.

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Digital health technologies (DHT) are computing platforms, software, Internet-connected devices and sensors that are used for healthcare and related uses [1]. They include smartphone applications, network-connected wearable devices, web-based communication platforms, videoconferencing, chatbots, artificial intelligence (AI) and virtual reality (VR) technology. Although physicians have utilized computers and digital technologies for decades, the increasing availability of portable networked devices has opened a new frontier that will improve access to, and quality of, care provided to patients. The potential for DHT to disrupt healthcare delivery is reflected by a 91% increase in venture capital funding from US\$7.4 billion in 2019 to an all-time record of \$14.1 billion in 2020 [2].

Patients with cancer are more likely to have frequent follow-ups and hospitalizations, and they are more likely to suffer from treatment toxicities and psychological disorders [3]. Their complex care involves multidisciplinary coordination of medical, surgical and psychological treatments, as well as overall wellness (exercise and nutritional support). With such complexity of care and while suffering from the side effects of cancer and its treatment, these patients may have even more to gain from digital adjuncts to their medical care [4]. Digital solutions for cancer care are expected to perform relatively simple (e.g., encouraging diet and exercise) and complex (detailed counseling on screening and treatment) tasks. Furthermore, DHT enable the collection of large amounts of data, which may be integrated into personalized treatment AI-powered algorithms. Therefore, the authors sought to conduct a narrative review of DHT that outlines how clinicians may augment the care they provide by organizing DHT by purpose or utility, which offers a complimentary perspective to others – for example, organized by type of DHT (e.g., chatbot, wearable, web-based platform) [5–9]. The authors thus describe DHT used to improve cancer screening and shared decision-making, patient education, promotion of positive health habits, symptom monitoring and intervention, psychological support and delivery of effective survivorship care.

Methods

Articles and studies that employed DHT to improve the cancer care of pediatric or adult patient populations were reviewed. The broadest definition of DHT was used, including many forms of technology with Internet connectivity. These included computers, smartphones and tablets with associated applications, web-based platforms, media and interactive tools. Other DHT included were network-enabled wearable devices (watches, rings, chest straps, etc.) and non-wearable devices (smart scales, smart water bottles, blood pressure cuffs, etc.), allowing for the transfer of biometric user information from patients to physicians. Communication platforms were also included, such as video/telecommunication, allowing for bidirectional information transfer; chatbots; and intelligent assistants, which rely on natural language processing to interact with people in a conversational manner, provide information and respond to concerns through personalized voice or text messages [10]. Other forms of DHT included were AI and machine learning software, VR, digital storytelling and video gaming. References from previously published reviews of DHT used in cancer care were also cross-referenced, and content experts provided additional studies for review. Articles discussed in this narrative review were hand-selected for variety to portray the extent of digital technologies employed in contemporary oncologic care.

Discussion

Cancer screening & shared decision-making

DHT may provide more convenient, accessible and informed cancer screening. For example, teledermatology enables patients to take a picture of their lesion for evaluation by a physician. A recent systematic review of 21 web-based teledermatology skin cancer screening services revealed a slightly decreased diagnostic accuracy compared with face-to-face dermatologic care (51–85%, Cohen's κ : 0.41–0.63% vs 67–85%, Cohen's κ : 0.9) but reduced wait times and improved patient satisfaction [11]. The study also showed that patients were willing to pay out of pocket for digital care. Thus, as the diagnostic accuracy improves, DHT will greatly improve access to and quality of care.

The decision on whether to screen for some cancers such as prostate and breast cancer is controversial, so current guidelines emphasize shared decision-making [12,13]. After the COVID-19 pandemic, which has led to a 60–82% decrease in screening tests for cancer [14], DHT may have a facilitated screening to catch up on missed cancer diagnoses. For instance, compared with usual care, web-based programs have been shown to help men make decisions about prostate cancer screening, increase patient knowledge about the disease (standard mean difference [SMD]: 0.46; 95% CI: 0.18–0.75), reduce decisional conflict (SMD: -7.07%; 95% CI: -9.44–4.71), and facilitate shared decision-making (relative risk [RR]: 0.50; 95% CI: 0.31–0.81) [15]. To improve patient–provider communication and bidirectional flow of information, a web-based platform ranks prostate cancer treatment options based on clinical factors and patient preferences. With this, patients felt more involved and responsible for the treatment decision than patients who received usual care [16]. Furthermore, a recent systematic review and meta-analysis revealed that the use of social media and mobile DHT was associated with increased odds (odds ratio [OR]: 1.49; 95% CI: 1.31–1.70) for breast, cervical, colorectal, lung and prostate cancer screening [17], although consideration for the appropriateness of screening should also be evaluated. Chatbots, which are fully automated conversational agents that use software and often AI to converse via text or text-to-speech, may also be used to facilitate information transfer between patient and physician [18]. The chatbot iDecide promotes informed prostate cancer screening decisions among racial minorities [19]. Similarly, a chatbot developed by the Cleveland Clinic Foundation has been used to communicate with patients undergoing routine colonoscopy to determine whether heritable cancer syndrome screening is indicated [20]. Overall, cancer screening is an ongoing process requiring patients to present for care many times over their lives, and it may be complicated by a personal or family history of cancer as well as lifestyle factors such as smoking or sun exposure. Overall, DHT may improve cancer outcomes by increasing access to screening, improving cancer-related patient education and empowering patients through shared decision-making, thereby becoming integral in the future of healthcare.

Patient education

Processing a cancer diagnosis can be extraordinarily difficult for patients, and information about cancer and treatment options is the service most frequently requested by patients [3]. Evidence indicates that patients over the past 40 years have been dissatisfied with the information they receive, but their anxiety decreases when information is provided [3]. Experts posit that patient-targeted information should be delivered in diverse ways depending on patient diagnosis, preferences, expectations and stage of treatment [3]. Reviews have consistently demonstrated

a multitude of smartphone- and web-based platforms to provide tailored cancer education such as providing descriptions of surgical procedures, risks and benefits of surgery, postoperative complications and wound care and quality of life [9,21,22]. In a review of web-based education programs for men with prostate cancer, the majority of men reported a significant increase in their knowledge of the disease as well as their satisfaction with the treatment options and support offered [23]. Additionally, chatbots have been used to provide patient education. Physicians in France built Chatbot Vik to empower patients with breast cancer by responding to fears and concerns through personalized text messages [10]. A non-inferiority randomized controlled trial (RCT) demonstrated that Chatbot Vik was as good as physicians at providing quality information to breast cancer patients (69% vs 65% satisfaction; $p < 0.001$) [10]. Given that information should be delivered in a variety of ways, web-, smartphone- and chatbot-based platforms should be continually improved to educate patients about their cancer diagnosis, set expectations and explain treatment options. Equally important, information delivery methods should consider differences in health literacy, cultural preferences and the social determinants of health [24,25].

Promotion of positive health behaviors

Research shows that physical activity, a healthy diet and weight control play a role in the quality of life and longevity of cancer survivors [26]. Accordingly, physicians are expected to promote healthy living behaviors. However, many physicians have a limited ability to address these behaviors during time-limited patient visits [27]. Thus, physicians may utilize DHT to promote healthy habits beyond the confines of the clinic. For example, among adult cancer survivors, web- and Facebook-based interventions aimed at increasing moderate-to-vigorous activity showed improvement in physical activity [28,29], psychological outcomes [29] and weight loss [28]. Another weight-loss mobile application used a healthcare provider interface to improve anthropometrics (weight, body mass index and weight circumference) among overweight and obese endometrial and breast cancer survivors [30]. Additionally, differences in patient preferences and health literacy must be considered [31], and combining more than one digital health technology may be associated with better results. For instance, African-American breast cancer survivors were randomized to a wireless scale that provided monitored and tailored feedback about weight; a wireless scale plus an activity tracker and a control group [32]. Median weight changes were -0.2%, -0.9% and +0.2%, respectively, with the group with the wireless scale and activity tracker demonstrating the largest weight loss. Nevertheless, a fitness tracker was not as efficient in improving physical activity among children and young adults [33]. Alternatively, in this young age category, a weight management intervention using web, phone and text messages tailored for overweight and obese leukemia survivors demonstrated an increase in moderate-to-vigorous physical activity and less weight gain [34]. Other interesting interventions could be tailored for special populations. Sabel *et al.* demonstrated through a crossover study that active video gaming (Nintendo Wii) for children treated for brain tumors resulted in moderate physical activity and 15% improvement in body coordination score [35].

Wearable technologies tracking fitness provide doctors with a lens into patients' activity and functional status. As of 2019, it was estimated that 30% of Americans use wearable electronic devices to monitor or track their health or activity and 80% are willing to share this information with their healthcare provider [36]. This technology was leveraged to promote physical activity before major surgeries, as physical activity was shown to improve quality of life and postoperative outcomes when programs are designed with high-quality content [4,37,38]. Similar interventions were done before elective colorectal surgery, where increased activity was associated with decreased risk for any postoperative complication (27.5% vs 55.9%; $p = 0.005$) [39], and before lung cancer surgery, where patients who achieved >6000 steps/day during a physical exercise program were more likely to maintain increased physical activity long after surgery (52.2% vs 20.5%; $p = 0.0083$) [40]. Increased number of steps on postoperative day 5 was also associated with earlier discharge among patients with gastric cancer (OR: 2.72; 95% CI: 1.17–6.32; $p = 0.02$) [41]. Moreover, fitness trackers with tailored weekly goals were tested among children with acute lymphocytic leukemia; patients who achieved their activity goals were less likely to complain of fatigue after their corticosteroids pulse dose [42]. Other studies demonstrated an inverse correlation between patients' activity and the severity of symptoms (among patients undergoing hematopoietic cell transplant) [43] and hospitalization risk (among patients undergoing chemoradiation for different cancers) [44].

While patient-to-physician data transfer is used in research on exercise, the real potential of wearable devices in medicine is in facilitating bidirectional data transfer or communication and personalized patient care. Thus, doctors will be able to more effectively identify those in most need of intervention. For example, in a series of systematic reviews on pre-operative exercise programs, the quality and therapeutic validity of the program were improved when patients' physical activity data were shared with physical therapists and health coaches such that they could

adapt and personalize the exercise to the individual's needs, disabilities and preferences [4,37,38]. Similarly, in a study by Santa Mina *et al.* examining the benefits of exercise before radical prostatectomy, wearable wristwatches enabled physical therapists to monitor and adjust patients' training programs. Overall, the study demonstrated physical and psychological postoperative benefits from exercise [45]. Encouragingly, when combined with in-person coaching, wearables increased the likelihood of completing a 225-min-per-week activity program among women with ovarian cancer [46]. The utility of wearable technology in medicine will continue to increase with technological advancements and increases in the utilization of wearables, as well as comfortability sharing resultant data with healthcare providers.

Patient symptom monitoring & intervention

There is strong evidence that monitoring patient reported outcomes (PROs) and chemotherapy toxicities during cancer treatment improves outcomes such as the number of emergency admissions, hospitalizations and quality-adjusted survival [47–50]. Patients with cancer are a high-risk population that may benefit from continuous monitoring. DHT that enable ambulatory monitoring in these populations have great potential to reduce morbidity and mortality associated with cancer complications. They may also reduce costs due to avoidable readmissions and hospital stays.

The impact of such DHT monitoring for cancer complications comes from the ability to recognize and intervene upon warning signals. Symptoms easily overlooked (abdominal pain, diarrhea or sores around the anus) may signal worrisome chemotherapy toxicity or even neutropenia necessitating emergent medical care. Oncologists have leveraged web-based computerized platforms to enable real-time reporting of PROs [47,48], particularly among patients receiving chemotherapy. By adapting the National Cancer Institute's Common Terminology Criteria for Adverse Events to plain English, Basch *et al.* developed a web-based platform where patients are able to report chemotherapy toxicities from their home, before clinic visits [49]. Another RCT comparing symptom reporting on a tablet linked to email alerts to usual care, found an association between PRO reporting and decreased emergency room admissions (34% vs 41%; $p = 0.02$) and hospitalizations (45% vs 49%; $p = 0.08$) as well as improved quality-adjusted survival (mean: 8.7 vs 8.0 months; $p = 0.004$) [50].

Since DHT allow the collection of PROs in real time, they can, for example, be used to send nurses and physicians alerts via email or text message to notify them of symptoms that require a change in management. Pain is the most common symptom experienced in patients with cancer and has numerous etiologies (surgery, treatment side effects or cancer itself) reaching a prevalence of 65% in patients with advanced, metastatic or terminal disease [51]. Pain management is at the core of palliative care and has a direct impact on the patients' quality of life. Daily assessment of pain was successfully assessed among adolescents and adults either through interactive voice response messages on mobile devices or in algorithm-informed applications [52,53]. Nurses were notified in cases of moderate or severe pain and accordingly contacted the patients to assist in pain management and adapt the treatment. Others have investigated more complex systems for remote monitoring of patients' symptoms using home-based and mobile sensors, which show promise, given the technological advancements in recent years. For example, Peterson *et al.* monitored patients' vitals (blood pressure, heart rate and weight) to detect dehydration among patients who underwent radiotherapy for head and neck cancer [54]. Therefore, through the collection of health information, physicians can intervene early in the management of cancer treatment toxicities and ensure quality care for patients with cancer. Chatbot Penny is under development to provide text message-based bidirectional communication between clinicians and patients, longitudinal symptom monitoring with self-management support and motivational cues to promote medication adherence. Penny will remind patients how and when to take their oral targeted therapies, monitor side effects of treatment and provide self-management advice guided by clinical pathways [55].

Research has revealed various strategies to most effectively elicit the patient's perspective and translate PROs into informative data that physicians can use to improve treatment. Even in early studies, monitoring PROs improved the detection of adverse events in a timely manner compared with standard physician monitoring, which was neither sensitive nor specific (Cohen's κ : 0.15) [56]. Additionally, when patients use a computerized system to report their symptoms and preferences prior to a consultation, there is a 37% ($p < 0.0001$) greater congruence between the PROs reported by patients and the symptoms addressed by physicians [16]. Thus, physicians could enhance the patient's experience of cancer care by focusing on shared decision-making and by addressing the symptoms that are most bothersome to patients [16]. One common obstacle in web-based PRO reporting is compliance. It should be noted that patients have a higher compliance for monthly versus weekly PROs (83% vs 62%) and that compliance

improves with reminders and clinician feedback [49,57]. Furthermore, coaching patients on how to best report their symptoms and quality of life directly to physicians or through web-based questionnaires improved reporting of problematic symptoms compared with no coaching (85% vs 75%; $p = 0.0009$) [58]. Web-based questionnaires and iPhone/iPad applications have also been developed and shown to be effective among adolescents and young adults with cancer [59,60]. Adolescents and young adults had high compliance with digital health technology use for PRO reporting, as these devices empower them to communicate their experience with the provider [59,60]. Thus, iPad applications or websites may more effectively collect PROs (chemotherapy toxicities or pain) in this age group in the forms of diaries, graphical abstracts or games than in the form of standard survey instruments.

Psychological care

From 2019 to 2020, demand for improved access to mental healthcare drove a 2.9-fold increase (US\$609 million to \$1.8 billion) in investment in DHT funding [2]. While modern cancer care often focuses on state-of-the-art biomedical treatments, psychosocial problems (e.g., depression, anxiety) created or exacerbated by cancer can threaten the efficacy of such treatment by reducing adherence to treatment, cause additional stress and suffering and reduce quality of life [3]. Thus, cancer survivors may benefit from more psychological support than can be given within the confines of standard clinical visits with healthcare providers [3]. DHT can improve the delivery of psychological support to patients who live far from facilities, who are bound by physical limitations or who avoid face-to-face contact out of fear of contagion [61]. Traditional DHT, including text message- and telephone-based care, are successful at decreasing depressive symptoms [61]. More recently, web-based, smartphone, and videoconference platforms provide complex support, including screening and/or treatment reminders, connection to community resources and services, tailored information, cognitive behavioral therapy and e-communication with cancer nurses and group discussions [62–64]. A 1-year follow-up study of Chatbot Vik, which included 4737 breast cancer patients, demonstrated higher adherence to their treatment with increased engagement with Vik and overall 94% satisfaction with the support provided [65]. VR, a computer-generated simulation of a three-dimensional environment, has been used as a form of distraction during treatment among adolescents and adults [66–68]. A crossover RCT conducted among women receiving chemotherapy for breast cancer found that VR distraction was associated with a significant decrease in distress and fatigue symptoms directly after chemotherapy [67]. Among children and young adults, VR distraction or games were effective for pain, anxiety and depressive symptom reduction during treatment or hospitalization [66,68].

Psychosocial interventions are best personalized to the individual, customized to the disease and adapted to the stage of survivorship [63]. For example, one study found that multidisciplinary couples-based sexual rehabilitation after treatment for prostate cancer yielded improved International Index of Erectile Function and Female Sexual Function Index scores when administered both by a therapist in person and through a web-based format [69]. Alternatively, young cancer survivors may be particularly susceptible to psychosocial stressors associated with cancer treatment and may more readily adopt new or complex DHT than older populations. Weekly group videoconference for young adult cancer survivors over 2 months yielded improvements in body image, anxiety, depression, social isolation, posttraumatic growth, self-compassion and mindfulness [70]. Another study of adolescent and young adult cancer survivors who made digital stories with the help of a research assistant trained in digital storytelling anecdotally found this to be a way for survivors to understand their experiences with cancer, to allow for further healing from prior trauma and to reconcile past experiences with their current lives, and it provided other unexpected therapeutic effects [71]. There are even data to suggest that cancer survivors may self-regulate participation based on their own needs. A study found that young adult cancer survivors with lower self-reported “social capital” – connections or relationships with other cancer survivors and sources of social support from friends and family – had greater participation in a social networking program than those with stronger social capital and support systems [72]. Additional technologies, including AI technologies, show particular promise. Vivibot – a chatbot born out of University of California, San Francisco and Northwestern University – includes 4 weeks of positive psychology skills, daily emotion ratings, video and periodic feedback check-ins through Facebook Messenger [73]. An associated pilot RCT testing the use of this chatbot in young adults within 5 years of the completion of cancer treatment demonstrated a trend toward reduced anxiety versus control [73]. With rising demand for convenient mental healthcare, future innovation should focus on increasing access to such resources.

Table 1. Digital health technologies augmenting cancer care.

	Wearable devices: watches, rings, chest-straps	Non-wearable devices: smartphones, tablets, smart scales, smart water bottles, blood pressure cuffs	Websites, web platforms, media, interactive tools	SMS/text/telephone	Video-/teleconference	Artificial intelligence: chatbots	Emerging DHT: virtual reality, digital storytelling, video gaming
Cancer screening		[11,81]	[22]			[20]	
Patient education and shared decision-making		[9,21,75,76]	[15,16,23,74–76,91]			[10,19]	
Promotion of healthy behaviors	[39–42,45,46]	[30,32–34]	[28,29,33,34,91]	[34]			[35]
Patient symptom monitoring		[50]	[47–49,56–58]		[64]	[10,55]	
Symptom intervention		[52–54,92]	[91]			[55]	
Psychological support		[76]	[62,69,76]	[61,93]	[63,64,70,72]	[10,65]	[66–68,71,73]
Survivorship care			[74,75]	[76,78]	[79,80]		

DHT: Digital health technologies; SMS: Short message service.

Delivery of survivorship care

Limited work has been performed to identify cancer survivors' needs and develop effective strategies to meet them. To this end, the National Cancer Institute has stressed the importance of developing effective and tailored interventions that mitigate the short- and long-term adverse effects of cancer and its treatment, as well as strategies to deliver the most effective survivorship care [26]. Delivery of appropriate patient education is one such component of effective survivorship care, which has comparable efficacy whether delivered directly by a physician or through web-based and smartphone applications. For example, one study found that among adolescent and young adult cancer survivors, delivery of tailored information through the web was as effective as standard of care (physician counseling) at improving cancer knowledge [74]. Similarly, a systematic review of 37 web-based interventions designed to help cancer survivors manage the long-term effects and symptoms of cancer and its treatment (many of which provided 'peer-to-peer access' or 'an enriched information environment') demonstrated small to moderate effects on measured outcomes compared with standard care [75]. With limited time during clinic visits, patient education surrounding survivorship may be as effectively, but more efficiently, provided virtually through DHT.

Another component of survivorship care is directed at the caregivers of those with cancer. A systematic review of 24 telemedicine and web-based interventions for caregivers of people with cancer reported significant improvements, although with small effect sizes, in measured outcomes, including psychosocial well-being, behavioral outcomes and user satisfaction. The interventions most often involved telephone calls or web-based platforms to provide psychological support, coping strategies and information about managing patients' symptoms [76]. Given that perceived social support, network size and marital status are inversely associated with cancer mortality (25%, 20% and 12% relative risk reduction, respectively) [77], additional focus should be afforded to supporting the caregivers of those with cancer.

Follow-up is an integral component of survivorship care that has been transformed by the COVID-19 pandemic. Earlier studies demonstrated that nurse-led phone follow-up could replace in-clinic follow-up among patients who had received treatment for different cancers, as it resulted in equal effectiveness and patient satisfaction. More recent technologies have expanded the potential of telehealth [78]. For instance, telemedicine involves either real-time voice/video interaction or chat with the provider. It allows the bidirectional transfer of clinical data. It could be conducted instead of or synchronously with in-person care [79]. While cancer screening [14], treatment and follow-up [80] initially slowed during the COVID-19 pandemic, the field of healthcare pivoted to rely heavily on telemedicine to deliver timely care to cancer patients. Following the Centers for Medicare & Medicaid Services telehealth expansion and increased consumer pressure for on-demand healthcare technologies, including telehealth and virtual visits, 2020 saw US\$2.7 billion in venture capital investment in these technologies, a 300% increase from 2019 [2]. In 2018, Sirintrapun and Lopez published a guide on telemedicine in cancer care; they compiled evidence that telemedicine is at least equivalent to in-person care and has other benefits, including improved access to care as well as decreased costs [79]. These technologies have the potential to increase the quality and quantity of care that physicians are able to provide, without increasing the resources required (Table 1).

Conclusion

In summary, DHT are increasingly used throughout the cancer care continuum. They can be leveraged to improve cancer screening, patient education, shared decision-making and communication, as well as to promote healthy habits, monitor symptoms, provide intervention, deliver psychological support and facilitate effective survivorship care. DHT effectively extends the care physicians can provide by operating outside of limited clinic visit time. Although telephone and text messaging communications systems have been utilized the longest, web-based platforms and smartphone applications are now the most employed. Telemedicine has rapidly expanded over the past decade, especially secondary to the COVID-19 pandemic, and physicians will likely continue to use it extensively throughout the postpandemic era. Chatbots are a very new form of DHT used for various purposes across the cancer care continuum. Emerging DHT such as virtual reality, digital storytelling and video gaming are most often used to provide psychological support and patient education. The integration of data provided by increasingly popular wearable devices and patient questionnaires into machine learning algorithms have the potential to transform traditional healthcare into personalized medicine. To maximize the impact of such rapidly advancing technologies, experts must develop appropriate solutions to the regulation, liability, quality, security, reimbursement and equity problems of DHT.

Future perspective

Regulatory, liability, quality & privacy issues

While DHT have great potential to positively impact cancer care, several issues will need to be addressed to fully realize this potential, including regulatory oversight, liability, quality assurance and the security of DHT. Web-based platforms and smartphone applications are by far the most common type of DHT; however, the vast majority of these are not scrutinized by medical professionals or validated with results published in peer-reviewed journals; thus, the quality and reliability of the majority of these are questionable. For example, many smartphone applications are on the market for skin cancer screening, although a recent review reveals significant limitations of these applications [81]. Many applications assist patients in self-monitoring their moles or lesions over time, but most were developed without dermatologist input and are not validated. Regarding regulation, the Federal Trade Commission does not oversee medical devices. However, since its purpose is to protect consumers by stopping unfair, deceptive or fraudulent practices in the marketplace, it found two smartphone applications making unsupported claims about their applications diagnosing melanoma to be in violation of truth in advertising laws in 2015 [82]. Since that precedent, the US FDA published a “Mobile Medical Applications: Guidance for Industry and Food and Drug Administration Staff,” which specifies that regulatory oversight will only be enforced on mobile applications that meet the definition of a medical device in the Federal Food, Drug and Cosmetic Act. Medical devices are those that are intended for use in performing a medical device function and would cause harm to patients if it did not function properly [83]. Thus, few applications that claim to be medical devices are subject to FDA regulation, leaving the vast majority of health-related mobile applications unregulated. Indeed, one report revealed that only 100 out of 100,000 healthcare applications (0.1%) on the market in 2014 were FDA approved [84]. Most applications are unvalidated and have questionable methodologies in terms of regulation, provider selection (many employ non-licensed physicians) and privacy/security (few are Health Insurance Portability and Accountability Act [HIPAA] compliant) [11]. Furthermore, as few as 3% of the web-based programs state that the content has been evaluated by healthcare providers and only a quarter of them reference source information [9,21,23]. This is problematic because an unregulated digital health technology may provide false or misleading information to the consumer that could result in adverse outcomes without clear course for litigation. Quality assurance regulations are needed to improve the highest-quality platforms and reduce the quantity of low-quality platforms. Finally, data security is a critical issue, as so many DHT are specifically designed to collect sensitive patient information. Misuse of such data, or security breaches, could result in unwanted sharing or sale of personal information. Not only does this put patients in danger, but it also represents a serious threat to trust in the medical system. Given that the utility of machine learning scales with amount of data supplied, and that currently only 12% of smartphone applications are HIPAA compliant [85], it is critical that digital health technology security be improved. As more advanced technologies such as machine learning algorithms recommending specific treatments come onto the market, these issues could become more serious. Thus, DHT should be regulated with input from medical professionals with training to assure proper use. Unapproved third parties should not be permitted to give medical advice through DHT. Given the complexity of DHT, regulation will be difficult. For example, should AI be trusted to make clinical decisions?

Who is liable if a faulty decision is made? Given such complexity, multidisciplinary oversight with medical peer review must provide regulation on liability, quality assurance and data security.

Furthermore, DHT present new challenges related to reimbursements, parity and practice. There was a rapid expansion of telemedicine services to deliver timely access to cancer care throughout the COVID-19 pandemic, and given that these services are projected to stay, these issues must be addressed [79]. For example, if physicians are licensed in the state in which they practice, may they provide virtual care to patients physically located in other states? Should physicians be able to perform virtual visits with patients physically located in their licensing state when they themselves are located outside of it? How much can a virtual versus standard visit be reimbursed? Furthermore, many DHT focus on prevention and early detection. In a fee-for-service model, these kinds of services are disincentivized, while they may be favored in per capita or global payment models. Thus, reimbursement strategies should be aligned with healthcare priorities.

Equitable access to all these technologies is another area requiring critical analysis. Poverty, lack of access to DHT, poor engagement with digital health for some communities and barriers to digital health literacy have all been shown to contribute to lower access to care and poorer health outcomes [12,86], which may be addressed by the recently introduced Digital Health Equity Framework [24]. Increased adoption of DHT without considerations for historically marginalized populations may further widen existing disparities. Even for technologies designed for underserved populations, developers and researchers must be critical of their efficacy. For example, the chatbot iDecide, built out of the University of Southern Carolina, is a computer-based conversational agent designed to educate patients about prostate cancer screening and promote informed decision-making [25]. It was shown to enhance African Americans' intentions to engage in shared decision-making, but there was no subsequent evidence that it increased their likelihood of actually discussing prostate cancer treatment with a provider or participating in shared decision-making [25]. Therefore, DHT should be tailored to the cultural context and address the social determinants of health of the patient population just as they are tailored to the oncologic disease.

Integration to personalize treatment

We have highlighted modalities to collect various forms of data from cancer patients. However, to maximize efficacy, patient-level data on genomics, pathology, treatment and outcomes should be integrated with population-level cancer databases. It is only then that personalized treatment algorithms may be developed. Similarly, machine learning could be leveraged to develop AI-powered software able to identify which cancer treatment is the most effective for an individual with a specific combination of comorbidities, functional status and genetic aberrations. Such personalized medicine has been imagined for decades, but efforts are now being made and real progress is under way.

Several steps must be taken before AI may be maximally and most efficaciously integrated into modern cancer care. Large amounts of patient data must be collected, which requires patient buy-in and comfortability. To that end, agencies such as the European Network of Cancer Registries monitors and compiles cancer incidence and mortality data. These data are then utilized by registries to develop machine learning algorithms to improve patient care. For example, the European Cancer Image Platform (EuCanImagine) and the Interoperable Cancer Image Repository (INCIDIVE) are using these data to enhance the sensitivity and specificity of diagnostic radiology throughout the continuum of cancer care [87,88]. Another ongoing project, Big Data and Models for Personalized Head and Neck Cancer Decision Support (BD2Decide), is developing a model that combines patient-level data (clinical, pathologic, genomic, imaging and quality of life information) with epidemiologic data and clinical guidelines to guide decision-making for head and neck cancer treatment [89]. The BOUNCE project also builds on clinical, biological, lifestyle and psychosocial parameters to predict optimal psychosocial support strategies for women with breast cancer [90]. While modern clinical cancer guidelines do consider a limited amount of the same parameters in guiding treatment, AI will enable the inclusion of an unlimited amount of input data to develop much more complex personalized treatment algorithms aimed at improving outcomes.

The strength of this narrative review lies in its broad summary of the extant literature through a new lens, organizing DHT by purpose (e.g., screening, patient education, psychological care) such that clinicians and industry professionals may review technologies employed through each step of the cancer care continuum. This review offers a complimentary perspective to others – for example, organized by type of digital health technology (e.g., chatbot, wearable technology, web-based platform) [5]. The articles in this narrative review were selected to include the greatest variety of types of DHT for the greatest variety of purposes in order to provide a broad overview

of the state of the field. However, this approach does not allow for the kind of comprehensive analysis offered by reviews narrowed by type or purpose of DHT, especially those done in a systematic fashion [6–9].

Executive summary

- Utilization of digital health technology can be leveraged to support the full spectrum of cancer care.
- They improve cancer screening, patient education, shared decision-making, promotion of healthy habits, symptom monitoring and intervention, communication, provision of psychological support and delivery of effective survivorship care.

Future directions

- Integration of input data from digital health technologies (DHT) with clinical patient factors will enable the development of powerful machine learning algorithms to transform the future of personalized medicine.
- Only 0.1% of applications on the market are US FDA approved, 12% of smartphone applications are Health Insurance Portability and Accountability Act compliant and DHT are not regulated; experts must develop appropriate solutions to issues surrounding the regulation, liability, quality, security, equity and reimbursement of DHT.

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References

1. US Food and Drug Administration. What is digital health? (2021). www.fda.gov/medical-devices/digital-health-center-excellence/what-digital-health
2. DeSilva J, Zweig M. 2020 market insights report: chasing a new equilibrium. Rock Health (2020). <https://rockhealth.com/insights/2020-market-insights-report-chasing-a-new-equilibrium/>
3. Institute of Medicine (US) Committee on Psychosocial Services to Cancer Patients/Families in a Community Setting. *Cancer Care for the Whole Patient: Meeting Psychosocial Health Needs*. Adler NE, Page AEK (Eds). National Academies Press, DC, USA (2008).
4. Briggs LG, Reitblat C, Bain PA *et al*. Prehabilitation exercise before urologic cancer surgery: a systematic and interdisciplinary review. *Eur. Urol.* 81(2), 157–167 (2022).
5. Garg S, Williams NL, Ip A, Dicker AP. Clinical integration of digital solutions in health care: an overview of the current landscape of digital technologies in cancer care. *JCO Clin. Cancer Inform.* 2, 1–9 (2018).
6. Milne-Ives M, de Cock C, Lim E *et al*. The effectiveness of artificial intelligence conversational agents in health care: systematic review. *J. Med. Internet Res.* 22(10), e20346 (2020).
7. 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. Psych.* 64(7), 456–464 (2019).
8. Hong YA, Hossain MM, Chou WS. Digital interventions to facilitate patient-provider communication in cancer care: a systematic review. *Psychooncology* 29(4), 591–603 (2020).
9. Charbonneau DH, Hightower S, Katz A *et al*. Smartphone apps for cancer: a content analysis of the digital health marketplace. *Digit. Health* 6, 2055207620905413 (2020).
10. Bibault J-E, Chaix B, Guillemassé A *et al*. A chatbot versus physicians to provide information for patients with breast cancer: blind, randomized controlled noninferiority trial. *J. Med. Internet Res.* 21(11), e15787 (2019).
11. Finnane A, Dallest K, Janda M, Soyer HP. Teledermatology for the diagnosis and management of skin cancer: a systematic review. *JAMA Dermatol.* 153(3), 319–327 (2017).
12. Rutan MC, Sammon JD, Nguyen DD, Kilbridge KL, Herzog P, Trinh QD. The relationship between health literacy and nonrecommended cancer screening. *Am. J. Prev. Med.* 60(2), e69–e72 (2021).
13. Pucheril D, Dalela D, Sammon J *et al*. The influence of physician recommendation on prostate-specific antigen screening. *Urol. Oncol.* 33(10), 424.e1–424.e7 (2015).

14. Bakouny Z, Paciotti M, Schmidt AL, Lipsitz SR, Choueiri TK, Trinh Q-D. Cancer screening tests and cancer diagnoses during the COVID-19 pandemic. *JAMA Oncol.* 7(3), 458–460 (2021).
15. Baptista S, Teles Sampaio E, Heleno B, Azevedo LF, Martins C. Web-based versus usual care and other formats of decision aids to support prostate cancer screening decisions: systematic review and meta-analysis. *J. Med. Internet Res.* 20(6), e228 (2018).
16. Johnson DC, Mueller DE, Deal AM *et al.* Integrating patient preference into treatment decisions for men with prostate cancer at the point of care. *J. Urol.* 196(6), 1640–1644 (2016).
17. Ruco A, Dossa F, Tinmouth J *et al.* Social media and mhealth technology for cancer screening: systematic review and meta-analysis. *J. Med. Internet Res.* 23(7), e26759 (2021).
18. Brush K. What is a chatbot? (2021). <https://searchcustomerexperience.techtarget.com/definition/chatbot>
19. Owens OL, Felder T, Tavakoli AS *et al.* Evaluation of a computer-based decision aid for promoting informed prostate cancer screening decisions among African American men: iDecide. *Am. J. Health Promot.* 33(2), 267–278 (2019).
20. Heald B, Keel E, Marquard J *et al.* Using chatbots to screen for heritable cancer syndromes in patients undergoing routine colonoscopy. *J. Med. Genet.* 58(12), 807–814 (2020).
21. Wasserman M, Baxter NN, Rosen B, Burnstein M, Halverson AL. Systematic review of Internet patient information on colorectal cancer surgery. *Dis. Colon Rectum* 57(1), 64–69 (2014).
22. Acuna N, Vento I, Alzate-Duque L, Valera P. Harnessing digital videos to promote cancer prevention and education: a systematic review of the literature from 2013–2018. *J. Cancer Educ.* 35(4), 635–642 (2020).
23. Salonen A, Ryhänen AM, Leino-Kilpi H. Educational benefits of Internet and computer-based programmes for prostate cancer patients: a systematic review. *Patient Educ. Couns.* 94(1), 10–19 (2014).
24. Crawford A, Serhal E. Digital health equity and COVID-19: the innovation curve cannot reinforce the social gradient of health. *J. Med. Internet Res.* 22(6), e19361 (2020).
25. Owens OL, Kim S, Tavakoli AS. Are decision aids leading to shared prostate cancer screening decisions among African-American men?: iDecide. *Cancer Causes Control* 30(7), 713–719 (2019).
26. National Cancer Institute, U.S. Department of Health & Human Services. Cancer Survivorship: Addressing Complex Needs throughout the Lifespan. *National Institutes of Health* (2021). www.cancer.gov/research/annual-plan/2022-annual-plan-budget-proposal-aag.pdf#understanding-how-to-improve-the-delivery-of-survivorship-care
27. Wells M, Aitchison P, Harris F *et al.* Barriers and facilitators to smoking cessation in a cancer context: a qualitative study of patient, family and professional views. *BMC Cancer* 17(1), 348 (2017).
28. Valle CG, Tate DF, Mayer DK, Allicock M, Cai J. A randomized trial of a Facebook-based physical activity intervention for young adult cancer survivors. *J. Cancer Surviv.* 7(3), 355–368 (2013).
29. Rabin C, Dunsiger S, Ness KK, Marcus BH. Internet-based physical activity intervention targeting young adult cancer survivors. *J. Adolesc. Young Adult Oncol.* 1(4), 188–194 (2011).
30. McCarroll ML, Armbruster S, Pohle-Krausz RJ *et al.* Feasibility of a lifestyle intervention for overweight/obese endometrial and breast cancer survivors using an interactive mobile application. *Gynecol. Oncol.* 137(3), 508–515 (2015).
31. Nabi J, Cone EB, Vasavada A *et al.* Mobile health app for prostate cancer patients on androgen deprivation therapy: qualitative usability study. *JMIR Mhealth Uhealth* 8(11), e20224 (2020).
32. Valle CG, Deal AM, Tate DF. Preventing weight gain in African American breast cancer survivors using smart scales and activity trackers: a randomized controlled pilot study. *J. Cancer Surviv.* 11(1), 133–148 (2017).
33. Mendoza JA, Baker KS, Moreno MA *et al.* A Fitbit and Facebook mHealth intervention for promoting physical activity among adolescent and young adult childhood cancer survivors: a pilot study. *Pediatr. Blood Cancer* 64(12), doi:10.1002/pbc.26660 (2017).
34. Huang JS, Dillon L, Terrones L *et al.* Fit4Life: a weight loss intervention for children who have survived childhood leukemia. *Pediatr. Blood Cancer* 61(5), 894–900 (2014).
35. Sabel M, Sjölund A, Broeren J *et al.* Active video gaming improves body coordination in survivors of childhood brain tumours. *Disabil. Rehabil.* 38(21), 2073–2084 (2016).
36. Chandrasekaran R, Katthula V, Moustakas E. Patterns of use and key predictors for the use of wearable health care devices by US adults: insights from a national survey. *J. Med. Internet Res.* 22(10), e22443 (2020).
37. Hoogbeem TJ, Oosting E, Vrieseckolk JE *et al.* Therapeutic validity and effectiveness of preoperative exercise on functional recovery after joint replacement: a systematic review and meta-analysis. *PLoS One* 7(5), e38031 (2012).
38. Thomas G, Tahir MR, Bongers BC, Kallen VL, Slooter GD, Van Meeteren NL. Prehabilitation before major intra-abdominal cancer surgery: a systematic review of randomised controlled trials. *Eur. J. Anaesthesiol.* 36(12), 933–945 (2019).
39. Hedrick TL, Hassinger TE, Myers E *et al.* Wearable technology in the perioperative period: predicting risk of postoperative complications in patients undergoing elective colorectal surgery. *Dis. Colon Rectum* 63(4), 538–544 (2020).
40. Patel Y, Hylton D, Rok M *et al.* MA16.05 Wearable technology for preconditioning before thoracic surgery: a feasibility study. *J. Thoracic Oncol.* 14(10), S314 (2019).

41. Wu JM, Ho TW, Chang YT *et al*. Wearable-based mobile health app in gastric cancer patients for postoperative physical activity monitoring: focus group study. *JMIR Mhealth Uhealth* 7(4), e11989 (2019).
42. Hooke MC, Gilchrist L, Tanner L, Hart N, Withycombe JS. Use of a fitness tracker to promote physical activity in children with acute lymphoblastic leukemia. *Pediatr. Blood Cancer* 63(4), 684–689 (2016).
43. Bennett AV, Reeve BB, Basch EM *et al*. Evaluation of pedometry as a patient-centered outcome in patients undergoing hematopoietic cell transplant (HCT): a comparison of pedometry and patient reports of symptoms, health, and quality of life. *Qual. Life Res.* 25(3), 535–546 (2016).
44. Ohri N, Kabarriti R, Bodner WR *et al*. Continuous activity monitoring during concurrent chemoradiotherapy. *Int. J. Radiation Oncol. Biol. Phys.* 97(5), 1061–1065 (2017).
45. Santa Mina D, Hilton WJ, Matthew AG *et al*. Prehabilitation for radical prostatectomy: a multicentre randomized controlled trial. *Surg. Oncol.* 27(2), 289–298 (2018).
46. Zhang X, McClean D, Ko E, Morgan MA, Schmitz K. Exercise among women with ovarian cancer: a feasibility and pre-/post-test exploratory pilot study. *Oncol. Nurs. Forum* 44(3), 366–374 (2017).
47. Ruland CM, White T, Stevens M, Fanciullo G, Khilani SM. Effects of a computerized system to support shared decision making in symptom management of cancer patients: preliminary results. *J. Am. Med. Inform. Assoc.* 10(6), 573–579 (2003).
48. Pietanza MC, Basch EM, Lash A *et al*. Harnessing technology to improve clinical trials: study of real-time informatics to collect data, toxicities, image response assessments, and patient-reported outcomes in a phase II clinical trial. *J. Clin. Oncol.* 31(16), 2004–2009 (2013).
49. Basch E, Iasonos A, Barz A *et al*. Long-term toxicity monitoring via electronic patient-reported outcomes in patients receiving chemotherapy. *J. Clin. Oncol.* 25(34), 5374–5380 (2007).
50. Basch E, Deal AM, Kris MG *et al*. Symptom monitoring with patient-reported outcomes during routine cancer treatment: a randomized controlled trial. *J. Clin. Oncol.* 34(6), 557–565 (2016).
51. van den Beuken-van Everdingen MH, Hochstenbach LM, Joosten EA, Tjan-Heijnen VC, Janssen DJ. Update on prevalence of pain in patients with cancer: systematic review and meta-analysis. *J. Pain Symptom Manage.* 51(6), 1070–1090.e9 (2016).
52. Besse KT, Faber-te Bovelde ND, Janssen GH, Vernooij-Dassen M, Vissers KC, Engels Y. Pain assessment with short message service and interactive voice response in outpatients with cancer and pain: a feasibility study. *Pain Pract.* 16(3), 320–326 (2016).
53. Jibb LA, Stevens BJ, Nathan PC *et al*. Implementation and preliminary effectiveness of a real-time pain management smartphone app for adolescents with cancer: a multicenter pilot clinical study. *Pediatr. Blood Cancer* 64(10), e26554 (2017).
54. Di Maio M, Basch E, Bryce J, Perrone F. Patient-reported outcomes in the evaluation of toxicity of anticancer treatments. *Nat. Rev. Clin. Oncol.* 13(5), 319–325 (2016).
55. Katharine A, Rendle ST. Implementation strategies for monitoring adherence in real time (iSMART). ClinicalTrials.gov NCT04347161. <https://clinicaltrials.gov/ct2/show/NCT04347161>
56. Fromme EK, Eilers KM, Mori M, Hsieh Y-C, Beer TM. How accurate is clinician reporting of chemotherapy adverse effects? A comparison with patient-reported symptoms from the Quality-of-Life Questionnaire C30. *J. Clin. Oncol.* 22(17), 3485–3490 (2004).
57. Judson TJ, Bennett AV, Rogak LJ *et al*. Feasibility of long-term patient self-reporting of toxicities from home via the Internet during routine chemotherapy. *J. Clin. Oncol.* 31(20), 2580–2585 (2013).
58. Berry DL, Hong F, Halpenny B *et al*. The electronic self report assessment and intervention for cancer: promoting patient verbal reporting of symptom and quality of life issues in a randomized controlled trial. *BMC Cancer* 14, 513 (2014).
59. Baggott C, Gibson F, Coll B, Kletter R, Zeltzer P, Miaskowski C. Initial evaluation of an electronic symptom diary for adolescents with cancer. *JMIR Res. Protoc.* 1(2), e23 (2012).
60. Stinson JN, Jibb LA, Nguyen C *et al*. Development and testing of a multidimensional iPhone pain assessment application for adolescents with cancer. *J. Med. Internet Res.* 15(3), e51 (2013).
61. Casillas J, Goyal A, Bryman J *et al*. Development of a text messaging system to improve receipt of survivorship care in adolescent and young adult survivors of childhood cancer. *J. Cancer Surviv.* 11(4), 505–516 (2017).
62. Ruland CM, Andersen T, Jeneson A *et al*. Effects of an Internet support system to assist cancer patients in reducing symptom distress: a randomized controlled trial. *Cancer Nurs.* 36(1), 6–17 (2013).
63. Sansom-Daly U, Wakefield C, McGill BC, Patterson P. Ethical and clinical challenges delivering group-based cognitive-behavioural therapy to adolescents and young adults with cancer using videoconferencing technology. *Australian Psychologist* 50, 271–278 (2015).
64. Kroenke K, Theobald D, Wu J *et al*. Effect of telecare management on pain and depression in patients with cancer: a randomized trial. *JAMA* 304(2), 163–171 (2010).
65. Chaix B, Bibault JE, Pienkowski A *et al*. When chatbots meet patients: one-year prospective study of conversations between patients with breast cancer and a chatbot. *JMIR Cancer* 5(1), e12856 (2019).
66. Gershon J, Zimand E, Pickering M, Rothbaum BO, Hodges L. A pilot and feasibility study of virtual reality as a distraction for children with cancer. *J. Am. Acad. Child Adolesc. Psych.* 43(10), 1243–1249 (2004).

67. Schneider SM, Prince-Paul M, Allen MJ, Silverman P, Talaba D. Virtual reality as a distraction intervention for women receiving chemotherapy. *Oncol. Nurs. Forum* 31(1), 81–88 (2004).
68. Li WH, Chung JO, Ho EK. The effectiveness of therapeutic play, using virtual reality computer games, in promoting the psychological well-being of children hospitalised with cancer. *J. Clin. Nurs.* 20(15–16), 2135–2143 (2011).
69. Schover LR, Canada AL, Yuan Y *et al.* A randomized trial of Internet-based versus traditional sexual counseling for couples after localized prostate cancer treatment. *Cancer* 118(2), 500–509 (2012).
70. Campo RA, Bluth K, Santacroce SJ *et al.* A mindful self-compassion videoconference intervention for nationally recruited posttreatment young adult cancer survivors: feasibility, acceptability, and psychosocial outcomes. *Support. Care Cancer* 25(6), 1759–1768 (2017).
71. Laing CM, Moules NJ, Estefan A, Lang M. Stories that heal: understanding the effects of creating digital stories with pediatric and adolescent/young adult oncology patients. *J. Pediatr. Oncol. Nurs.* 34(4), 272–282 (2017).
72. McLaughlin M, Nam Y, Gould J *et al.* A videosharing social networking intervention for young adult cancer survivors. *Comput. Hum. Behav.* 28(2), 631–641 (2012).
73. 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* 7(10), e15018 (2019).
74. Kunin-Batson A, Steele J, Mertens A, Neglia JP. A randomized controlled pilot trial of a web-based resource to improve cancer knowledge in adolescent and young adult survivors of childhood cancer. *Psychooncology* 25(11), 1308–1316 (2016).
75. Kim AR, Park H-A. Web-based self-management support interventions for cancer survivors: a systematic review and meta-analyses. *Stud. Health Technol. Inform.* 216, 142–147 (2015).
76. Marzorati C, Renzi C, Russell-Edu SW, Pravettoni G. Telemedicine use among caregivers of cancer patients: systematic review. *J. Med. Internet Res.* 20(6), e223 (2018).
77. Pinquart M, Duberstein PR. Associations of social networks with cancer mortality: a meta-analysis. *Crit. Rev. Oncol. Hematol.* 75(2), 122–137 (2010).
78. Kimman ML, Bloebaum MM, Dirksen CD, Houben RM, Lambin P, Boersma LJ. Patient satisfaction with nurse-led telephone follow-up after curative treatment for breast cancer. *BMC Cancer* 10, 174 (2010).
79. Sirintrapun SJ, Lopez AM. Telemedicine in cancer care. *Am. Soc. Clin. Oncol. Educ. Book* 38, 540–545 (2018).
80. Sonagli M, Cagnacci Neto R, Leite FPM, Makdissi FBA. The use of telemedicine to maintain breast cancer follow-up and surveillance during the COVID-19 pandemic. *J. Surg. Oncol.* 123(2), 371–374 (2021).
81. Chao E, Meenan CK, Ferris LK. Smartphone-based applications for skin monitoring and melanoma detection. *Dermatol. Clin.* 35(4), 551–557 (2017).
82. Federal Trade Commission. FTC cracks down on marketers of “melanoma detection” apps (2015). www.ftc.gov/news-events/news/press-releases/2015/02/ftc-cracks-down-marketers-melanoma-detection-apps
83. US FDA. Policy for device software functions and mobile medical applications (2019). www.fda.gov/media/80958/download
84. Cortez NG, Cohen IG, Kesselheim AS. FDA regulation of mobile health technologies. *N. Engl. J. Med.* 371(4), 372–379 (2014).
85. Anastasiou A, Giokas K, Koutsouris D. Monitoring of compliance on an individual treatment through mobile innovations. *Annu. Int. Conf. IEEE Eng. Med. Biol. Soc.* 2015, 7320–7333 (2015).
86. Nguyen DD, Trinh QD, Cole AP *et al.* Impact of health literacy on shared decision making for prostate-specific antigen screening in the United States. *Cancer* 127(2), 249–256 (2021).
87. Font AG. Improving cancer diagnosis and prediction with AI and big data. <https://incisive-project.eu/about/> (Accessed 15 September 2021)
88. Lekadir K. EuCanImage – cancer imaging platform for enhanced Artificial Intelligence in oncology (2021). <https://radiomics.bio/eucanimage-project/#~:text=EuCanImage%20is%20a%204%2Dyear,under%20grant%20agreement%20No%20952103>
89. Lopez-Perez L, Hernández L, Ottaviano M *et al.* BD2Decide: big data and models for personalized head and neck cancer decision support. Presented at: 2019 IEEE 32nd International Symposium on Computer-Based Medical Systems (CBMS). 67–68 (2019).
90. European Commission. Predicting effective adaptation to breast cancer to help women to BOUNCE back. <https://cordis.europa.eu/project/id/777167> (Accessed 15 September 2021)
91. Kuijpers W, Groen WG, Aaronson NK, van Harten WH. A systematic review of web-based interventions for patient empowerment and physical activity in chronic diseases: relevance for cancer survivors. *J. Med. Internet Res.* 15(2), e37 (2013).
92. Ahmed I, Ahmad NS, Ali S *et al.* Medication adherence apps: review and content analysis. *JMIR Mhealth Uhealth* 6(3), e62 (2018).
93. Gotay CC, Bottomley A. Providing psycho-social support by telephone: what is its potential in cancer patients? *Eur. J. Cancer Care (Engl.)* 7(4), 225–231 (1998).