Published in final edited form as:

Am Soc Clin Oncol Educ Book. 2020 March ; 40: 1–7. doi:10.1200/EDBK_279505.

Toward Modernization of Geriatric Oncology by Digital Health Technologies

Armin Shahrokni, MD, MPH¹, Kah Poh Loh, MBBCh BAO², William A. Wood, MD³

¹Memorial Sloan Kettering Cancer Center, New York, NY

²James P. Wilmot Cancer Institute, University of Rochester School of Medicine and Dentistry, Rochester, NY

³Lineberger Comprehensive Cancer Center, University of North Carolina at Chapel Hill, Chapel Hill, NC

overview

The number of older adults with cancer is increasing. Over the past 3 decades, geriatric oncology research has focused on improving the assessment of frailty and fitness of older adults with cancer as well as methods of improving their outcomes. At the same time, advances in digital health technologies have opened new frontiers for reaching this goal. Digital health technologies encompass a variety of solutions, from electronic patient-reported outcomes (ePROs) to big data and wireless sensors. These solutions have the potential to further advance our understanding of patients' experiences during cancer treatment. Whereas the data on the feasibility and utility of such solutions in the care of older adults with cancer are limited, interest from digital health oncology researchers to further explore the benefits of these products is increasing. In this article, we describe the focus of geriatric oncology, the rationale behind the need to explore digital health technologies in this setting, and emerging data and ongoing studies, as well as provide guidelines for proper selection, implementation, and testing of digital health solutions in the context of geriatric oncology.

INTRODUCTION

It is no longer news that global aging is real.¹ It is also abundantly clear that cancer is still primarily a disease of aging populations.² In the past 3 decades, evidence has emerged that age alone should not be a factor in decision making, and tolerating treatment is not a function of age but rather a patient's frailty or lack of fitness.³ The gold standard by which to assess the fitness of older adults with cancer is geriatric assessment, a multidimensional assessment of older adults.³ On the basis of geriatric assessment and other simple clinical and laboratory results, statistical models with which to predict chemotherapy toxicities have been developed that predict outcomes much better than routine functional assessment

CORRESPONDING AUTHOR: Armin Shahrokni, MD, MPH, Geriatrics Service, Department of Medicine, Memorial Sloan Kettering Cancer Center, Box 205, 1275 York Ave., New York, NY 10065; Twitter: @MSK_GeriOnc; shahroka@mskcc.org.

AUTHORS' DISCLOSURES OF POTENTIAL CONFLICTS OF INTEREST AND DATA AVAILABILITY STATEMENT
Disclosures provided by the authors and data availability statement (if applicable) are available with this article at DOI https://doi.org/10.1200/EDBK_279505.

methods, such as the Karnofsky performance scale.⁴ Components of geriatric assessment are also associated with other outcomes, such as early mortality,⁵ surgical complications, and readmission.⁶ On the basis of this level of evidence, many organizations and societies, including ASCO, have published guidelines and recommendations for the implementation of geriatric assessment at each phase of cancer care.^{7,8}

Although geriatric oncology has advanced with the promotion of more comprehensive assessment and care of older adults with cancer, technology—mainly web-based and wireless technologies—has also advanced. Digital health technology⁹ encompasses multiple platforms, such as ePROs, either web or application based, wearables and sensors, and remote monitoring tools, such as smart homes. Whereas the feasibility, acceptability, and utility of such platforms in all disease-related contexts remain under investigation, the promise of such tools in geriatric oncology is worthy of more attention.

As discussed above, the main concept of geriatric oncology is to assess frailty or a lack of fitness of older adults with cancer. Until now, such an assessment mainly occurred in the outpatient clinic setting; however, older adults with cancer spend little of their time in clinics, even during chemotherapy. Instead, they spend the majority of their time at home. It is during this time that symptoms, adverse effects from medical cancer treatment, or complications from surgery are more likely to emerge. Without timely diagnosis and management of severe symptoms, a fit patient can become frail between clinic visits, leading to hospitalization and a further decrease in fitness level. A decline in fitness of older adults with cancer may be more problematic for those with poor social support, especially those patients who do not have someone to take them to doctor appointments, because these patients are at higher risk for under-reporting their chemotherapy toxicity.¹⁰ Traditionally, other methods, such as visiting nursing services or relying on care-givers/patients to call via phone, have been used to fill such gaps in care; however, emerging digital health technologies may also assist in filling the gap. Another use for such tools is the ability to collect a vast and useful amount of data from older adults with cancer before, during, and after treatment that can provide real-world and precise information about the challenges and outcomes of older adults with cancer as they receive cancer-related treatments.

In this article, we will describe the opportunities and challenges of using these solutions for modernizing geriatric oncology.

OLDER ADULTS AND ACCEPTANCE OF DIGITAL HEALTH TECHNOLOGIES

Digital health technologies have become increasingly prevalent, but their utility, feasibility, and roles may differ in older and younger adults. According to the Pew Research Center, in 2017, approximately 42% of adults age 65 and older reported owning smartphones, which increased from 18% in 2013.¹¹ In addition, 67% of adults age 65 and older reported having internet access, 42% reported having home broadband, 32% reported having tablets, and 34% reported using social media.¹¹ It is important to note that use decreased with age (i.e., 59% in those age 65 to 69 reported owning a smartphone, and 17% of those age 80 and older reported owning a smartphone).¹¹ However, these numbers have steadily increased and will

continue to with the increasing familiarity of older adults with technology as well as the growth of the population.

Not all older adults are afraid of technology. In a survey conducted by the Pew Research Center, two distinct groups of older adults in the United States were identified. The younger, more educated, and wealthier group was more likely to use technology devices and have a favorable view of them. In contrast, the older, less wealthy, and more comorbid group was more disconnected from the digital world.¹² Nevertheless, most older adults are willing to learn and adopt new technology^{13,14} and should therefore not be left out.

CHALLENGES TO THE USE OF DIGITAL HEALTH TECHNOLOGIES FOR OLDER ADULTS

There are several challenges that older adults face when adopting technology devices. It is essential to consider these challenges in both the clinical and research settings. First, many older adults are not confident in their ability to learn and use technology devices, in part because of their perception that the technology is too complicated¹⁴; therefore, proactive approaches to increase support for this population (e.g., instruction manuals, videos, and staff) are needed. Simple technology devices are also preferred.¹⁴ Second, older adults are more likely to have impairments that serve as barriers to using technology devices.¹⁵ For example, touchscreen devices may be challenging for those with visual impairment, but this barrier may be mitigated by large-print keyboard and screen-reading features.¹⁵ Such features as larger font sizes, bigger icons, and magnification are also helpful in this population. Despite this known challenge with touchscreen interfaces, there is less of a performance gap between older and younger adults with touchscreens compared with keyboards and mice.¹⁶ Such findings indicate that touchscreens are an attractive option for older adults. Older adults are also less anxious when using touchscreens versus a standard keyboard terminal.¹⁷ Third, certain older adults are skeptical about the importance of technology devices.¹⁴ In this group, education about how the technology device gathers information and how the health care team uses the information they provide to guide their management and care may help reinforce their adoption.

BIG DATA TO SHED LIGHT ON REAL-WORLD OUTCOMES OF OLDER ADULTS WITH CANCER

Older adults with cancer are under-represented in clinical trials.¹⁸ Published clinical trials also under-report the outcomes of older adults with cancer who participate in those clinical trials.¹⁹ Moreover, the fitness of those who participate in clinical trials may not fully represent the fitness of average older adults with cancer in the community because of strict inclusion and exclusion criteria.²⁰ As a result, there is a need for alternative methods by which to assess the outcomes of older adults with cancer who resemble average older adults with cancer in the community.

Over the past decade, big data has emerged as a method of assessing the outcomes of patients with cancer in general and in older adults with cancer specifically. In general, we

define big data as large and complex data sets that grow so rapidly that existing analytical tools fail to take advantage of the full potential of big data.²¹ The CancerLinQ project, which started in 2012 and is led by ASCO, is probably the most prominent initiative to develop oncologic big data.²² With the goal of rapid learning from patients and their outcomes, CancerLinQ goals are to collect and aggregate data from patient records, analyze the data, and develop real-time decision support systems for clinicians, as well as to explore the data to generate relevant hypotheses. In 2015, CancerLinQ was officially implemented and adopted by 85 community and academic oncology practices.²³ Additional progress was made by linking CancerLinQ to other data sets, such as the National Cancer Institute Surveillance, Epidemiology, and End Results program.²⁴ Recently, data are emerging on the utility of CancerLinQ to better understand the outcomes of patients with cancer and their contributing factors. For example, using the CancerLinQ data set, the prevalence of autoimmune disease among patients receiving immune checkpoint inhibitors (ICIs) was assessed. The prevalence of autoimmune disease was between 23% and 27% for patients with lung cancer and other patients who were receiving ICIs—much higher than expected, especially because a majority of clinical trials for ICIs exclude patients with autoimmune diseases.²⁵ As a result, CancerLinQ provides a great opportunity to better understand the outcomes of older adults who receive ICIs despite having autoimmune diseases.

As older adults with cancer become more tech savvy, many health care institutions are transforming their paper-format questionnaires to electronic and web-based formats for ease of data capturing. At Memorial Sloan Kettering Cancer Center, geriatric assessment has been converted into a web-based questionnaire and named electronic rapid fitness assessment (eRFA).²⁶ A pilot study on more than 600 older adults with cancer demonstrated that eRFA can be completed in approximately 10 minutes, and an overwhelming majority of older adults with cancer expressed their satisfaction with completing eRFA in the geriatrics clinics.²⁶ Subsequently, Memorial Sloan Kettering Cancer Center thoracic surgery and bone marrow transplantation services successfully implemented eRFA at a point of care.^{27,28}

ePROs are another method with which to capture a large amount of data inside and outside of clinics, which can be useful for both research and clinical practice.²⁹ Investigators have shown that the use of ePROs for assessing and subsequently managing symptoms improves the quality of life and overall survival of patients.^{30,31} However, with participants' median age of 62, the feasibility and efficacy of ePROs for older adults with cancer was unknown. To address this question, Nipp and colleagues³² performed a secondary analysis and found that overall survival and the rate of emergency room visits were similar between older adults with cancer who were reporting their symptoms via ePRO and those who were observed by routine care. In contrast, the use of ePROs has led to a reduction in hospitalization and an improvement in quality of life. This study highlights the need for additional exploration and expansion of ePROs for the assessment and care of older adults with cancer, especially outside of clinical trials in which participants are more similar to average older adults with cancer in the community.

SELECTION AND USE OF WEARABLE SENSORS IN ONCOLOGY PRACTICE

Although digital health technologies have the potential to augment clinical care and research in older adults with cancer, many oncologists are uncertain about how to evaluate and implement these technologies in practice. Here, we propose a practical guide for the oncology researcher or clinician. We focus the discussion on sensors and specifically on those that are part of connected biometric monitoring technologies (BioMeTs).³³ We focus on BioMeTs as these types of devices and systems, which can capture continuous physiologic data from patients for prolonged periods, are probably the most relevant to potential use cases in older adults with cancer. A BioMeT can detect and monitor one or more metrics, such as activity, sleep, heart rate, heart rhythm, respiratory rate, and others.

When considering the deployment of a BioMeT in research or practice, it is essential to first consider the potential context of use and, from there, the health concept of interest. Then, potential metrics that are needed to measure this health concept of interest at baseline and over time can be identified. In the setting of geriatric oncology, as noted earlier in this work, potential contexts of use include baseline frailty assessments (e.g., comprehensive geriatric assessments³⁴ or eRFAs)³⁵ and monitoring for functional deterioration or adverse events between clinic visits. The best current example of the latter is likely home-based ePRO monitoring,³¹ although the robustness of this approach in older individuals with cancer is still being evaluated.³²

Measuring Physical Function With BioMeTs

To augment the use of baseline frailty assessments and between-visit monitoring, a BioMeT that specifically evaluates physical function may be of interest. An abundance of literature highlights the capacity of physical function or performance status to predict morbidity, resource utilization, and mortality in patients with cancer.^{36–39} A frailty assessment, at its root, has the exploration of participant physical function, and between-visit deterioration or adverse events can reasonably be expected to correlate with concurrent physical function changes. Thus, in characterizing baseline physical function and changes in function over time, much like an early warning system,^{40,41} a BioMeT could augment the current roles of frailty assessments and PRO monitoring.

Once a health concept of interest has been identified, one or more metrics that help to measure this concept should be ascertained. In some cases, the best metrics may not be obvious, and additional development may be needed to construct composite measures derived from BioMeTs. Physical function is likely to be an example of this. On the basis of previous research, we know that physical activity is related to physical function, and thus a measure of activity (e.g., steps per day) at baseline and over time can tell us something about a participant's function.⁴² However, we also know that activity is behaviorally influenced and that the relationship between function and activity is not entirely overlapping. Modern BioMeTs contain additional information that can help to correct for this. For example, resting heart rate, heart rate response to activity increases or decreases, respiratory variation as a function of heart rate and activity, and other physiologic data are related to physical

function,^{43,44} are obtainable from BioMeTs,⁴⁵ and could be included within a BioMeT-derived physical function measure. Furthermore, other types of clinical outcomes assessments may also provide nonoverlapping data to give additional precision around physical function assessment, such as self-reported physical function (e.g., PROMIS^{46,47}), or the results of periodic standardized physical assessments, such as a 6-minute walk test⁴⁸ or short physical performance battery.^{49,50} In other words, it may be possible to construct a model around physical function prediction that includes, but is not limited to, data from BioMeTs while incorporating information from other clinical outcomes assessments.

Selecting Connected Health Technologies That Are Fit for Purpose

When a health concept of interest (e.g., physical function) and potential metrics of interest (e.g., activity, heart rate, or respiratory rate) have been identified, a user can start to look for a device that is fit for purpose to collect the identified metric(s). Here, it is essential to note that the marketplace is filled with a variety of connected sensor technologies that exist throughout consumer-oriented and health-directed spaces. The quality of data that these sensors generate is variable, and some connected sensor technologies have other vulnerabilities or concerns that limit their appropriateness for use with research or clinical participants. Several organizations have attempted to develop frameworks to evaluate whether a device is fit for purpose. One such framework includes five key dimensions for evaluation: validation, security practices, data rights and governance, utility and usability, and economic feasibility.³³

In this framework, validation is used as a shorthand for a three-stage process of verification, analytical validation, and clinical validation, collectively known as V3.⁵¹ Verification refers to sample-level data generated by a sensor within a BioMeT against a prespecified set of criteria. Analytical validation looks at how well the BioMeT component algorithms perform in measuring, detecting, or predicting physiologic metrics. Finally, clinical validation determines whether the BioMeT identifies, measures, or predicts a meaningful clinical, biologic, physical, functional state, or experience in a specified population and context of use. Without a robust V3 process, it is difficult to ascertain the quality and reliability of data generated by a sensor and associated BioMeT. Security practices refers to the degree to which a BioMeT is protected from unauthorized access and attacks, including human error. Data rights and governance concern such processes as end-user license agreements, terms of service, and privacy policies, which specify the rights of users and the ability of device manufacturers to monitor, aggregate, and share users' digital biospecimens. Utility and usability help to determine whether a BioMeT has the features that users need and evaluate the user experience with these features. These include human factor considerations, such as battery life, water resistance, form, user interface, and other issues. Finally, economic feasibility refers to the business model and fees of the sensor, which may include a subscription or long-term fees around data storage and analysis. Many frameworks, such as that described here, include ways to evaluate how a candidate-connected sensor technology performs against the five dimensions and may include visualizations to help understand this, like a nutrition label for a particular technology or a side-by-side comparison.

Considerations for Analytic Plans and Study Designs Using Connected Sensor Technologies

After a fit-for-purpose technology has been identified, the user must determine an analytic plan for measuring the health concept of interest using the chosen metrics with the fit-for-purpose technology. This is not an easy task considering that large volumes of data are continuously generated from these devices. Missing data are often a concern, as is the context within which the data are generated, as well as their comparisons to gold standard metrics.⁵² Furthermore, as in our example of physical function, how to combine metrics to appropriately measure the concept of interest is not always obvious. Pilot studies may be appropriate for model development and follow-up validation studies before deploying the composite metric in a larger population as part of a larger study. Machine learning techniques may facilitate the aggregation and modeling of high dimensionality, multivariable data, such as that generated by connected sensor technologies.⁵³

After these steps, it is critical to develop an appropriate study design and enrollment and monitoring strategy. This is especially true with connected sensor technologies, as a variety of factors influence adherence to wearing the BioMeT and the willingness of sites and participants to participate in a project involving these technologies. The Clinical Trials Transformation Initiative, a public/private partnership with a mission to “develop and drive adoption of practices that will increase the quality and efficiency of clinical trials,”⁵⁴ recently developed recommendations around optimizing mobile clinical trials by engaging patients and sites.⁵⁵ When considering the deployment of BioMeTs in geriatric oncology, a researcher or clinician might not have a multicenter clinical trial in mind. With that said, the Clinical Trials Transformation Initiative recommendations, which cover topics that include engaging patients and sites in planning clinical trials using mobile technology (e.g., protocol design, technology selection, and pilot testing), maximizing value and minimizing burden for study participants (e.g., setting expectations, protecting privacy, returning individual data, enhancing participant-site interactions, and providing technical support), and addressing challenges for investigative sites (e.g., contracting and budgeting recommendations, evaluating site readiness, and implementing practical and streamlined training), may still be instructive in planning for any study that involves connected sensor technologies.

At one of our institutions (University of North Carolina), we have followed this basic framework in developing a health coaching program for patients with cancer or survivors of cancer of all ages. Participants undergo baseline evaluation, which includes several components that are similar to geriatric assessment remote PRO assessment, including symptoms, physical function, and unmet needs during treatment and survivorship; and BioMeT deployment, with regular monitoring of activity, heart rate, and other metrics. With this program, we can concurrently develop composite metrics of physical function from the BioMeTs using data iteratively acquired from participants throughout our 6-month intervention.

EMERGING DATA ON THE USE OF DIGITAL HEALTH TECHNOLOGIES FOR OLDER ADULTS WITH CANCER

Several studies have investigated or are currently investigating the use of digital health technologies for older adults with cancer. Their functions may include one or more of the following: monitor cancer- and treatment-related adverse effects; monitor vital signs, such as blood pressure, weight, and sleep; manage daily activities (e.g., medications and appointments); provide education; and promote healthy lifestyles (e.g., physical activity). Studies in the oncology setting have been previously summarized, and we highlight studies that are specific to older adults with cancer.⁹

In terms of wearable sensors, in a pilot study of 40 adults age 65 and older starting first-line chemotherapy, Soto and colleagues⁵⁶ found that using a smartphone with a pedometer application to monitor daily steps was feasible. If patients had a decline in daily steps, they were contacted for assessment of symptoms and chemotherapy-related toxicity. A randomized controlled trial is currently ongoing ([ClinicalTrials.gov](https://clinicaltrials.gov/ct2/show/study/NCT04040881) identifier: [NCT04040881](https://clinicaltrials.gov/ct2/show/study/NCT04040881)).

Three studies evaluated mobile health applications in older adults with cancer. In the first study of 18 older adults receiving cancer treatment and their caregivers, a tablet-based system was used to deliver interventions on the basis of geriatric assessment impairments.¹⁵ For example, if a patient has impairment in physical function, he or she was educated about energy conservation and exercise and were asked to track daily steps. If patients were on five or more medications or screened positive for cognitive impairment, medication monitoring was instituted. The intervention was demonstrated to be feasible and usable. Loh and colleagues¹⁵ also found challenges specific to older adults that were used to adapt the intervention, including reliable internet access; providing a stylus; and incorporating nonmedical functions, such as daily jokes or words, to increase motivation. Hong and colleagues⁵⁷ evaluated an interactive mobile-enabled web app to promote physical activity among older survivors of cancer in a single-arm pilot. Of the 26 patients, two patients were on active treatment. Participants had overall positive experiences with the mobile app, with improvement found in self-rated health, quality of life, and sleep quality. Specific suggestions to improve the system include automated functions (e.g., an ability to enter activity automatically). Finally, a third study evaluated the differential effects of an electronic symptom monitoring intervention for patients with advanced cancer. Nipp and colleagues found that older adults may not derive the same benefits from an electronic symptom monitoring intervention as younger adults.³² Specifically, both the older and younger populations in the intervention arm had lower risks of hospitalization and better quality of life, but emergency room visits and survival were similar between the intervention and control arms in the older age group. This study highlights the need to tailor technology-based interventions to the unique needs of older adults.

CONCLUSION

Advances in technology and digital health solutions provide a great opportunity to further advance the field of geriatric oncology. However, additional studies are needed to explore proper solutions, context, patient population, and outcomes.

ACKNOWLEDGMENT

Dr. Loh receives support from the National Cancer Institute (K99CA237744) and Wilmot Research Fellowship Award. This work was supported by the Memorial Sloan Kettering Summer Research Fellowship Grant 5R25CA020449 and National Institutes of Health/National Cancer Institute Cancer Center Support Grant P30CA008748.

REFERENCES

1. Daniels N. *Global Aging and the Allocation of Health Care Across the Life Span*. Abingdon, United Kingdom: Taylor & Francis; 2013.
2. White MC, Holman DM, Boehm JE, et al. Age and cancer risk: a potentially modifiable relationship. *Am J Prev Med*. 2014;46:S7–S15. [PubMed: 24512933]
3. Korc-Grodzicki B, Sun SW, Zhou Q, et al. Geriatric assessment as a predictor of delirium and other outcomes in elderly patients with cancer. *Ann Surg*. 2015; 261:1085–1090. [PubMed: 24887981]
4. Hurria A, Mohile S, Gajra A, et al. Validation of a prediction tool for chemotherapy toxicity in older adults with cancer. *J Clin Oncol*. 2016;34:2366–2371. [PubMed: 27185838]
5. Soubeyran P, Fonck M, Blanc-Bisson C, et al. Predictors of early death risk in older patients treated with first-line chemotherapy for cancer. *J Clin Oncol*. 2012; 30:1829–1834. [PubMed: 22508806]
6. Kristjansson SR, Nesbakken A, Jordhøy MS, et al. Comprehensive geriatric assessment can predict complications in elderly patients after elective surgery for colorectal cancer: a prospective observational cohort study. *Crit Rev Oncol Hematol*. 2010;76:208–217. [PubMed: 20005123]
7. Mohile SG, Dale W, Somerfield MR, et al. Practical assessment and management of vulnerabilities in older patients receiving chemotherapy: ASCO guideline for geriatric oncology. *J Oncol Pract*. 2018;14:442–446. [PubMed: 29932846]
8. Extermann M, Aapro M, Bernabei R, et al. Use of comprehensive geriatric assessment in older cancer patients: recommendations from the task force on CGA of the International Society of Geriatric Oncology (SIOG). *Crit Rev Oncol Hematol*. 2005;55:241–252. [PubMed: 16084735]
9. Fallahzadeh R, Rokni SA, Ghasemzadeh H, et al. Digital health for geriatric oncology. *JCO Clin Cancer Inform*. 2018;2:1–12.
10. Shahrokni A, Sun CL, Tew WP, et al. The association between social support and chemotherapy-related toxicity in older patients with cancer. *J Geriatr Oncol*. 2020;11:274–279. [PubMed: 31501014]
11. Badgwell B, Stanley J, Chang GJ, et al. Comprehensive geriatric assessment of risk factors associated with adverse outcomes and resource utilization in cancer patients undergoing abdominal surgery. *J Surg Oncol*. 2013;108:182–186. [PubMed: 23804149]
12. Carneiro D, Novais P, Pêgo JM, et al. Using mouse dynamics to assess stress during online exams In: *International Conference on Hybrid Artificial Intelligence Systems*. Bilbao, Spain: Hybrid Artificial Intelligent Systems; 2015; pp 345–356.
13. Hoogland AI, Mansfield J, Lafranchise EA, et al. eHealth literacy in older adults with cancer. *J Geriatr Oncol*. Epub 2020 1 6.
14. Vaportzis E, Clausen MG, Gow AJ. Older adults perceptions of technology and barriers to interacting with tablet computers: a focus group study. *Front Psychol*. 2017;8:1687. [PubMed: 29071004]
15. Loh KP, Ramsdale E, Culakova E, et al. Novel mHealth app to deliver geriatric assessment-driven interventions for older adults with cancer: pilot feasibility and usability study. *JMIR Cancer*. 2018;4:e10296. [PubMed: 30373733]

16. Findlater L, Froehlich J, Fattal K, et al. Age-Related Differences in Performance with Touchscreens Compared to Traditional Mouse Input In CHI 2013. Paris, France: Association for Computing Machinery; 2013;343–346.
17. Umemuro H Lowering elderly Japanese users' resistance towards computers by using touchscreen technology. *Univers Access Inf Soc*. 2004;3:276–288.
18. Hurria A, Levit LA, Dale W, et al. Improving the evidence base for treating older adults with cancer: American Society of Clinical Oncology statement. *J Clin Oncol*. 2015;33:3826–3833. [PubMed: 26195697]
19. BrintzenhofeSzoc K, Krok-Schoen JL, Canin B, et al. The underreporting of phase III chemotherapeutic clinical trial data of older patients with cancer. *J Geriatr Oncol*. Epub 2020 1 10.
20. Kim ES, Bruinooge SS, Roberts S, et al. Broadening eligibility criteria to make clinical trials more representative: American Society of Clinical Oncology and Friends of Cancer Research joint research statement. *J Clin Oncol*. 2017;35:3737–3744. [PubMed: 28968170]
21. Andreu-Perez J, Poon CC, Merrifield RD, et al. Big data for health. *IEEE*. 2015;19:1193–1208.
22. Sledge GW Jr., Miller RS, Hauser RJ. CancerLinQ and the future of cancer care. *Am Soc Clin Oncol Educ Book*. 2013;33:430–434.
23. Rubinstein SM, Warner JL. CancerLinQ: origins, implementation, and future directions. *JCO Clin Cancer Infor*. Epub 2018 2 16.
24. Rivera D, Rubinstein WS, Schussler NC, et al. NCI and ASCO CancerLinQ collaboration to advance quality of cancer care and surveillance. *J Clin Oncol*. 2019;37: 15s (suppl; abstr e18317).
25. Chen L, Walker MS, Zhi J, et al. Real-world prevalence of autoimmune disease (AD) among patients (pts) receiving immune checkpoint inhibitors (ICI) in ASCO's CancerLinQ database. *J Clin Oncol*. 2019;37:15s (suppl; abstr 6583).
26. Shahrokni A, Tin A, Downey RJ, et al. Electronic rapid fitness assessment: a novel tool for preoperative evaluation of the geriatric oncology patient. *J Natl ComprCanc Netw*. 2017;15:172–179.
27. Lin RJ, Dahi PB, Shahrokni A, et al. Feasibility of a patient-reported, electronic geriatric assessment tool in hematopoietic cell transplantation—a single institution pilot study. *Leuk Lymphoma*. 2019;60:3308–3311. [PubMed: 31226901]
28. Downey RJ, Korc-Grodzicki B, Weber R, et al. Assessing the clinical feasibility of implementing a novel assessment of frailty: the electronic rapid fitness assessment in diverse thoracic surgery clinics. *J Clin Oncol*. 2017;35:15s (suppl; abstr e21687).
29. Jensen RE, Snyder CF, Abernethy AP, et al. Review of electronic patient-reported outcomes systems used in cancer clinical care. *J Oncol Pract*. 2014;10:e215–e222. [PubMed: 24301843]
30. Basch E, Deal AM, Dueck AC, et al. Overall survival results of a trial assessing patient-reported outcomes for symptom monitoring during routine cancer treatment. *JAMA*. 2017;318:197–198. [PubMed: 28586821]
31. Basch E, Deal AM, Kris MG, et al. Symptom monitoring with patient-reported outcomes during routine cancer treatment: a randomized controlled trial. *J ClinOncol*. 2016;34:557–565.
32. Nipp RD, Horick NK, Deal AM, et al. Differential effects of an electronic symptom monitoring intervention based on the age of patients with advanced cancer. *Ann Oncol*. 2020;31:123–130. [PubMed: 31912785]
33. Coravos ADM, Doerr M, Goldsack J, et al. Modernizing and designing evaluation frameworks for connected sensor technologies in medicine. *NPJ Digit Med*. 2020;3:37. [PubMed: 32195372]
34. Hurria A, Cirrincione CT, Muss HB, et al. Implementing a geriatric assessment in cooperative group clinical cancer trials: CALGB 360401. *J Clin Oncol*. 2011; 29:1290–1296. [PubMed: 21357782]
35. Shahrokni A, Tin A, Downey RJ, et al. Electronic rapid fitness assessment: a novel tool for preoperative evaluation of the geriatric oncology patient. *J Natl Compr Canc Netw*. 2017;15:172–179. [PubMed: 28188187]
36. Atkinson TM, Andreotti CF, Roberts KE, et al. The level of association between functional performance status measures and patient-reported outcomes in cancer patients: a systematic review. *Support Care Cancer*. 2015;23:3645–3652. [PubMed: 26314706]

37. Evers PD, Logan JE, Sills V, et al. Karnofsky performance status predicts overall survival, cancer-specific survival, and progression-free survival following radical cystectomy for urothelial carcinoma. *World J Urol.* 2014;32:385–391. [PubMed: 23756991]
38. Sorror M, Storer B, Sandmaier BM, et al. Hematopoietic cell transplantation-comorbidity index and Karnofsky performance status are independent predictors of morbidity and mortality after allogeneic nonmyeloablative hematopoietic cell transplantation. *Cancer.* 2008;112:1992–2001. [PubMed: 18311781]
39. Su J, Barbera L, Sutradhar R. Do repeated assessments of performance status improve predictions for risk of death among patients with cancer? A population-based cohort study. *Palliat Med.* 2015;29:547–553. [PubMed: 25634629]
40. Fringer A, Arrer E, Maier E, et al. Development of an early warning system to prevent crises in the palliative home care setting of patients and their informal caregivers: protocol for a mixed method study. *JMIR Res Protoc.* 2019;8:e13933. [PubMed: 31778114]
41. Hu SB, Wong DJ, Correa A, et al. Prediction of clinical deterioration in hospitalized adult patients with hematologic malignancies using a neural network model. *PLoS One.* 2016;11:e0161401. [PubMed: 27532679]
42. 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.* 2016;25:535–546. [PubMed: 26577763]
43. Groarke JD, Mahmood SS, Payne D, et al. Case-control study of heart rate abnormalities across the breast cancer survivorship continuum. *Cancer Med.* 2019;8:447–454. [PubMed: 30578624]
44. Ha D, Malhotra A, Ries AL, et al. Heart rate variability and heart rate recovery in lung cancer survivors eligible for long-term cure. *Respir Physiol Neurobiol.* 2019;269:103264. [PubMed: 31376471]
45. Perez MV, Mahaffey KW, Hedlin H, et al.; Apple Heart Study Investigators. Large-scale assessment of a smartwatch to identify atrial fibrillation. *N Engl J Med.* 2019; 381:1909–1917. [PubMed: 31722151]
46. Jensen RE, Potosky AL, Reeve BB, et al. Validation of the PROMIS physical function measures in a diverse US population-based cohort of cancer patients. *Qual Life Res.* 2015;24:2333–2344. [PubMed: 25935353]
47. Jensen RE, Potosky AL, Moinpour CM, et al. United States population-based estimates of patient-reported outcomes measurement information system symptom and functional status reference values for individuals with cancer. *J Clin Oncol.* 2017;35:1913–1920. [PubMed: 28426375]
48. Enright PL. The six-minute walk test. *Respir Care.* 2003;48:783–785. [PubMed: 12890299]
49. Klepin HD, Geiger AM, Tooze JA, et al. Geriatric assessment predicts survival for older adults receiving induction chemotherapy for acute myelogenous leukemia. *Blood.* 2013;121:4287–4294. [PubMed: 23550038]
50. Guralnik JM, Simonsick EM, Ferrucci L, et al. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. *J Gerontol.* 1994;49:M85–M94. [PubMed: 8126356]
51. Goldsack J. Verification, analytical validation, and clinical validation (V3): the foundation of determining fit-for-purpose for biometric monitoring technologies (BioMeTs). *NPJ Digit Med.* In press.
52. Izmailova ES, Wagner JA, Perakslis ED. Wearable devices in clinical trials: hype and hypothesis. *Clin Pharmacol Ther.* 2018;104:42–52. [PubMed: 29205294]
53. Meng Y, Speier W, Shufelt C, et al. A machine learning approach to classifying self-reported health status in a cohort of patients with heart disease using activity tracker data. *IEEE J Biomed Health Inform.* 2020;24:878–884. [PubMed: 31199276]
54. Tenaerts P, Madre L, Archdeacon P, et al. The Clinical Trials Transformation Initiative: innovation through collaboration. *Nat Rev Drug Discov.* 2014;13:797–8. [PubMed: 25359366]
55. Clinical Trials Transformation Initiative. CTTI recommendations: optimizing mobile clinical trials by engaging patients and sites. <https://www.ctti-clinicaltrials.org/sites/www.ctti-clinicaltrials.org/>

[files/ctti_recommendations_-_mct_engaging_patients_and_sites_final.pdf](#). Accessed March 18, 2020.

56. Soto-Perez-De-Celis E, Kim H, Rojo-Castillo MP, et al. A pilot study of an accelerometer-equipped smartphone to monitor older adults with cancer receiving chemotherapy in Mexico. *J Geriatr Oncol*. 2018;9:145–151. [PubMed: 29017891]
57. Hong YA, Goldberg D, Ory MG, et al. Efficacy of a mobile-enabled Web app (iCanFit) in promoting physical activity among older cancer survivors: a pilot study. *JMIR Cancer*. 2015;1:e7. [PubMed: 28410158]

PRACTICAL APPLICATIONS

- To properly apply digital health technology to research or clinical practice in older adults with cancer, carefully consider appropriate measurement concepts, fit for purpose technologies, analytic plan, and study designs.
- Big data plays a vital role in defining the real-world experience of older adults with cancer during treatment.
- Both opportunities and challenges for digital health in geriatric oncology are significant.