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## Wearable Technology and Physical Activity in Chronic Disease: Opportunities and Challenges

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### INTRODUCTION

Increased physical activity (PA) is associated with the prevention and delayed onset of many noncommunicable chronic conditions, such as heart disease, diabetes, and cancer, and health benefits, for example reduced risk of disease progression, secondary chronic conditions, and mortality, for individuals with chronic conditions.<sup>1</sup> PA is also associated with reduced cognitive dysfunction and functional limitations and enhanced mental health and quality of life.<sup>2</sup> Thus, identifying strategies to increase activity in high-risk individuals, as in those with at least one major risk factor, and those with chronic conditions remains a priority.

An abundance of technological devices exist to collect and analyze PA data and support the health of high-risk individuals and those with chronic conditions. Devices that are worn on the person, consumer-targeted, and worn continuously to quantify motion during the 24 hour day offer many promising opportunities to advance chronic disease research and clinical practice. These “wearables” include fitness bands, smart watches, and jewelry that log users’ activity metrics (i.e., step counts, energy expenditure) plus a range of other physiological and behavioral factors and can be used with a tablet/smartphone app or website that provides

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users with a summary of collected data. Wearables are designed and marketed as tools to motivate users to increase PA to improve health by allowing them to easily self-monitor behavior, a key element to successful behavior change.<sup>3</sup>

In 2013, 84 million wearables were sold; one in ten Americans own a device<sup>4</sup> and annual sales are projected to be >\$50 billion by 2018.<sup>5</sup> This burgeoning industry has been met with both excitement and skepticism. Wearables represent a scalable opportunity to collect activity data in free-living conditions, unobtrusively, with greater frequency, lower cost, and higher volume than ever before.<sup>6</sup> Wearables have significant potential to facilitate improvements in health behaviors. However, their capacity to translate external motivations into internal ones for sustainable behavioral changes and clinical value is still unknown.<sup>3</sup>

This article aims to: (1) summarize current and potential uses for wearables; (2) discuss challenges to using wearables; and (3) identify future directions for researchers and clinicians for chronic disease prevention and management.

## **CURRENT AND POTENTIAL USES FOR WEARABLES IN CHRONIC DISEASE PREVENTION AND MANAGEMENT**

Studies suggest wearables have adequate validity and reliability for activity measurement, use in chronic disease populations is feasible, and most individuals are open to sharing device data with researchers and healthcare systems.<sup>7,8</sup> Thus, this is an opportune time to integrate wearables into diverse contexts. Table 1 details potential uses for wearable-derived data for chronic disease research and management within two domains: epidemiological and health promotion.

### **Epidemiological**

Epidemiological uses of wearables for chronic disease development and management include: monitoring activity; describing activity context and correlates; and tracking individual disease trajectories (e.g., return to activity post-surgery).

Epidemiological studies typically rely on self-reported PA estimates, which, generally, have low to moderate validity.<sup>9</sup> Over the past decade, the introduction of accelerometers, valid and reliable tools for measuring activity,<sup>10</sup> into epidemiological studies has provided fine-grained data on individual movement patterns. However, limited battery capacity results in short, “snapshot” monitoring periods, typically 7 days. Because fluctuations in activity across weeks and months are not captured, information is missed that may be important when planning to intervene. Wearables can be recharged by the user or have coin cell batteries (last 12 months) translating to continuous, objective, real-time activity data can be collected over longer time periods resulting in greater insight into activity patterns across time. Finally, although data extracted from most wearables (via the application programming interfaces developed by device manufacturers) is crude compared with data extracted from research grade accelerometers, wearables exhibit adequate validity in comparison with research-grade monitors<sup>11</sup> and are more cost efficient making them an attractive alternative for larger studies. Total duration and activity accrual patterns likely vary over the course of disease progression or treatment. Wearables can be used across different chronic disease

trajectory phases (e.g., pre-versus post-surgery) and linked to medical record data to obtain granular data on how activity frequency, intensity, and duration changes over the disease course and with different treatments. These data could be used to identify crucial intervention time points.

Understanding who is likely to be physically active in different contexts is key to any successful intervention. Wearables provide an opportunity to better understand PA determinants and preferences in real-world settings over chronic conditions' trajectories to identify specific intervention targets. Combining wearable data with clinical data, patient-reported outcomes (i.e., motivation, symptoms), remote monitoring sensors (i.e., GPS, blood pressure, glucose, body weight), and social media data collected using Ecological Momentary Assessment methodology could provide a more comprehensive, multidimensional understanding of PA across the disease continuum. Ecological Momentary Assessment involves repeated sampling of subjects' current behaviors and experiences in real time in subjects' natural environments. Analysis of these data highlights individual differences in behavior, their distribution over time, factors affecting behavior and the mutual associations between them.<sup>11</sup> Combining wearable data with Ecological Momentary Assessment data from these other sources could provide more accurate information about activity fluctuations' antecedents and outcomes and new insight into potential intervention timing, targets, and high-risk subgroups. For example, these methods could reveal individuals engage in less activity on days they report greater fatigue. Thus, researchers may want to design interventions to increase activity and reduce fatigue.

Little is known about how activity patterns before, during, and after medical treatments predict health outcomes. As daily activity may be a proxy of overall health and functioning,<sup>12</sup> granular data from wearables could be combined with clinical (i.e., hospitalizations, disease progression markers) or functional (i.e., fitness, strength, balance) data to identify onset of disease or functional limitations prior to clinical symptoms. For example, activity may decline prior to hospitalization or with disease complication (i.e., edema, neuropathy) onset. Activity patterns may also be an indicator of symptoms, treatment adherence and short- and long-term disease prognosis.<sup>13</sup> Activity may decline more rapidly prior to disease onset or in individuals with a more aggressive disease. Changes in activity may also be indicative of treatment-related side effects resulting in poorer treatment adherence. Consequently, PA data from wearables could be used to monitor disease onset, treatment adherence, and predict prognostic outcomes amongst high-risk and chronic disease populations in the hospital and outpatient setting.

To date, machine learning algorithms have been developed to predict functional status including post-surgery body area changes in movement, walking stability, gait speed, and fall detection<sup>14</sup> using research-grade accelerometer and gyroscope data. As wearables' storage capacity increases, more data could be collected and used to refine algorithms to track high-risk individuals and identify activity patterns changes indicative of increased complications, more rapid disease progression, poor treatment adherence or disease self-management. Finally, combining wearables, clinical, and functional data with biological datasets (e.g., genomewide association study data; NIH precision medicine initiative) could

provide greater insight into interactions between genetics and behavior in disease onset and progression.

### Health Promotion

A review of behavior change techniques in 13 wearables and their associated mobile apps<sup>15</sup> found they use many of the same techniques employed in typical PA behavior change interventions (i.e., self-monitoring, goal-setting, social support). Additionally, individuals with chronic conditions perceive wearables as useful and acceptable.<sup>16</sup> Thus, wearables may be a low-cost, feasible, and accessible way for promoting PA. However, most existing efficacious wearables studies provide other behavior change supports including social support, financial incentives, and health coaching.<sup>17</sup> Hence, wearables' ability, alone, to produce clinically meaningful, sustained changes in activity without external motivation and accountability (e.g., reporting progress to study team) in high-risk individuals and those with chronic conditions, is unknown.<sup>3</sup> This is similar to the limited efficacy of providing a scale without additional support for weight loss. Wearables integration within a theory-driven intervention strategy should be carefully considered as wearables, by themselves, will not work for all individuals for a variety of reasons (i.e., demographics, psychosocial factors, motivation) and may need to be combined with additional intervention components. Adopting a stepped-care approach to provide additional intervention tools and supports to those who need them may be necessary to observe meaningful, sustained behavior change.

### Cancer Prevention and Control Case Study

Wearables could be implemented and integrated into clinical practice as a monitoring and intervention tool. Table 2 provides example research questions and clinical implications of answering these questions across the themes addressed within this section using cancer prevention and control as a case study. Briefly, wearables may allow for more personalized care and targeted interventions delivered with optimal timing to improve health and quality of life for high-risk individuals and those with chronic conditions.

### Challenges and Future Directions

Significant work is needed to understand the best and most efficient ways to fully integrate wearables into care (Table 3). However, in the future it is possible that wearables data are able to be used in conjunction with other data sources to increase PA, improve health and disease outcomes, and reduce healthcare costs. Figure 1 depicts what this ideal could look like. The relationships between activity data obtained from wearables and data related to disease progression, intermediary endpoints and disease outcomes obtained from other data sources could be integrated and examined unidirectionally and bidirectionally by individual characteristics to identify high-risk individuals for early intervention. These big datasets could be used to create more precise and effective multi-level (i.e., individual, systems wide) PA interventions with oversight from clinical and research staff to increase activity, improve health and disease outcomes and lower healthcare costs for high-risk individuals and those with chronic conditions.

To reach this ideal, many challenges must be overcome related to the: (1) participant/patient, (2) devices, and (3) clinical/research settings (Table 3). Engaging multi-level and -sector

stakeholders from the outset can help circumvent many challenges. Understanding individual patient perspectives on the burden of intensive data collection methods is important. Further, understanding clinicians' interest in wearable data and preferences for data presentation is necessary. Wearables developers should also be engaged, in the event activity output or algorithms are needed. Finally, researchers should work with health information specialists and statisticians to develop methods to integrate and harmonize data from wearables and other sources and sensors.

An important challenge is how to derive meaningful outcomes from wearables data, alone, and combined with other data sources to inform clinical decision making. Currently, machine learning approaches are being employed to make sense of the large data volume from wearables using research-grade devices primarily under controlled laboratory conditions. The next step is applying algorithms to free-living data from commercially available devices. This will support intervention research and the ability to understand the magnitude of changes in PA observed via wearables needed for health improvements.

Understanding how to use data from wearables to monitor and predict PA and disease or condition onset will create innumerable opportunities to provide patients with proactive interventions to prevent disease, reduce severity or control progression to a clinical syndrome. Building methods for just-in-time adaptive interventions to intervene on activity in real time based on patient profiles, real-world triggers (i.e., proximity to gyms), patient-reported outcomes (i.e., high fatigue, low motivation) or activity data itself (i.e., not meeting activity threshold by noon) should be a priority.<sup>18</sup> Additionally, innovative study designs including single case designs, multiphase optimization strategy,<sup>19</sup> and sequential multiple assignment designs<sup>19</sup> should be used to identify and adapt the most effective PA intervention components, or component sequence, to understand what works for whom, in what contexts, for what outcomes. Finally, dynamic systems modeling methods can help maximize just-in-time adaptive interventions delivery and make better use of intensive longitudinal data from wearables combined with potential intervention mediators.<sup>20</sup>

## CONCLUSIONS

Wearables offer an unobtrusive way to collect rich data on PA. These data can be linked to other data sources and used to help monitor and promote activity behavior change and maintenance. Despite wearables' promise, many questions and challenges need to be overcome (Tables 2 and 3) before they can be leveraged to enhance clinical care and improve health outcomes in high-risk individuals and those with chronic conditions. Studies using innovative methodology to understand whether these devices can be used for the purposes discussed are needed. Further, engaging diverse researchers (i.e., exercise science, public health, bioinformatics, statistics, methodology) and stakeholders (i.e., patients, clinicians, electronic health record and wearable companies' representatives) to understand challenges with using wearables and discover solutions is important. Ultimately, addressing these issues is central to leveraging wearables to improve public health, clinical care, and health outcomes and reduce disease risk, burden, and healthcare costs.

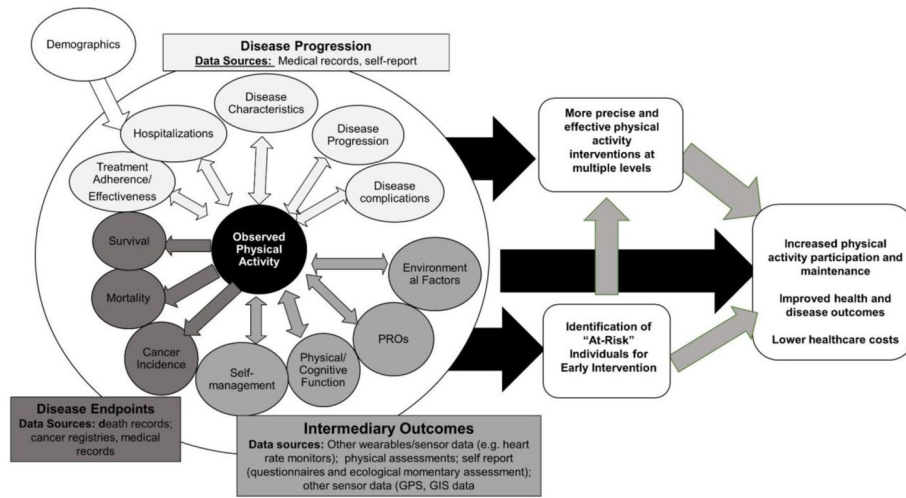
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**Figure 1.** Conceptual model of how wearables could ideally be integrated into research and clinical practice for chronic disease prevention and management.

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**Table 1****Current and Potential Uses for Wearables Within Chronic Disease Management in Clinical and Research Settings**

<b>Domain</b>	<b>Current and potential uses</b>
Epidemiological	<p>Monitoring and assessing physical activity</p> <ol style="list-style-type: none"> <li>1 Real-time, continuous assessment of PA over long periods of time, in large samples.</li> <li>2 Observe natural changes in PA through the disease course.</li> </ol> <p>Understanding context and correlates of PA</p> <ol style="list-style-type: none"> <li>1 Understand who is more or less likely to be physically activity in different contexts.</li> <li>2 Better understand PA preferences, frequency, intensity and duration in different contexts.</li> <li>3 Aggregated with other data sources to understand predictors and outcomes of activity behavior.</li> </ol> <p>Understanding individual disease trajectories</p> <ol style="list-style-type: none"> <li>1 Understand how activity patterns change pre-diagnosis, and as a result of different treatments or disease progression.</li> <li>2 Provide insight into disease progression.</li> <li>3 Identify potentially more effective timing, targets and subgroups for intervention.</li> <li>4 Understand whether predictors and outcomes of PA vary by patient or disease characteristics.</li> <li>5 Aggregate wearable data with other data sources to develop models to predict outcomes of interest (e.g., adverse events, disease progression, and functional decline).</li> <li>6 Data could be used as a proxy of overall health status to help inform clinical treatment decision making.</li> </ol>
Health promotion	<ol style="list-style-type: none"> <li>1 Given to patients or research participants as tool to facilitate PA behavior change and/or maintenance.</li> <li>2 Given to patients or research participants in combination with other intervention or program components to facilitate PA behavior change and/or maintenance.</li> <li>3 Combine data with data from other sources (i.e., sensor, patient reported outcome, clinical) to better time, target and tailor PA promotion interventions or programs.</li> </ol>

PA, physical activity

**Table 2**

Potential Clinical Implications of Using Wearables in Chronic Disease Management: Cancer Prevention and Control Case Study

Domain	Example research questions	Potential clinical implications
Epidemiological	Monitoring and assessing PA	<p><b>1</b> If integrated into EHR, ability to “Flag” high-risk patients for additional observation, testing or clinical or behavioral intervention to promote PA. Individuals who are meeting PA could also be indicated to reinforce behavior or indicate other risk factors may be a greater priority.</p> <p><b>2</b> More personalized treatment decisions.</p> <p><b>3</b> More accurate predictions of treatment side effects or outcomes.</p> <p><b>4</b> More accurate prediction of disease prognosis.</p> <p><b>5</b> Targeted interventions could be developed/delivered to those at highest risk.</p> <p><b>6</b> Specific factors that may impact PA (i.e., fatigue, depression) could be identified and treated.</p>
	<b>1</b> How does activity change over the course of cancer treatment?	
	<b>2</b> How do activity patterns change in a specified time period (i.e., 6 months, 1 year) following treatment?	
	<b>3</b> How do PA patterns change in a specified time period (i.e., 6 months, 3 months) before cancer diagnosis?	
	<b>4</b> Is physical inactivity in issues for a specific individual, population or subgroup?	
	Understanding context and correlates of PA	
	<b>1</b> What behavioral, psychosocial, or clinical factors influence changes in PA?	
	<b>2</b> Do activity patterns vary by treatment type (i.e., surgery, chemotherapy, radiation, hormonal therapy) and/or dose?	
	<b>3</b> Do activity pattern changes vary by disease characteristics (i.e., stage, time since diagnosis, recurrence status)?	
	<b>4</b> Are activity pattern changes related to patient reported outcomes (i.e., fatigue, depression) or motivational factors (i.e., self-efficacy, outcome expectations)?	
	Understanding individual disease trajectories	
	<b>1</b> Are PA patterns related to cancer diagnosis in high-risk groups?	
	<b>2</b> Are PA pattern changes prior to, during, or following treatment indicative of worse treatment outcomes?	
	<b>3</b> Are PA pattern changes prior to, during, or post treatment related to disease recurrence?	
	<b>4</b> Can PA pattern changes predict hospitalizations or other adverse events?	
	<b>5</b> Are PA pattern changes at specified time period predictive of functional outcomes, persistence of negative side effects, or disease prognosis?	
	<b>6</b> Are PA pattern changes related to treatment adherence, tolerance, or efficacy?	
	PA promotion	
<b>2</b> Could wearable PA data be used to predict cancer diagnosis prior to onset of clinical symptoms?		<b>2</b> Wearables could be given to cancer patients to help them maintain or increase their PA depending on treatment time point.
<b>3</b> Does giving cancer patients undergoing treatment wearables devices reduce typically observed activity decline?		<b>3</b> Data from wearables could be integrated into patient charts so clinicians could follow-up with them and check-in on their progress.
<b>4</b> Does giving cancer patients undergoing treatment wearable devices improve their health outcomes?		
<b>5</b> What is the optimal timing to give a patient a wearable device?		

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Domain	Example research questions	Potential clinical implications
	6 Does a wearable device impact PA participation long-term?	

PA, physical activity; EHR, electronic health record

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**Table 3**

## Challenges and Future Directions in Using Wearables in Research and Clinical Settings

Participant/Patient challenges	Challenges	Potential solutions/Future directions
Participant/Patient	<ul style="list-style-type: none"> <li>• Technology knowledge and skills and other individual barriers</li> <li>• Access to necessary technology for device to function (i.e., smartphone, tablet, computer)</li> <li>• Willingness to wear/burden of data collection</li> <li>• Motivation for behavior change</li> <li>• Adherence to wearable protocols</li> <li>• Reactivity to wearing the device in observational studies</li> <li>• Desensitization to feedback in intervention protocols</li> <li>• Habituation or loss of enthusiasm as the device's novelty wanes</li> <li>• Inability to afford wearable device</li> <li>• May not provide enough of an impetus for significant behavior change and maintenance</li> </ul>	<ul style="list-style-type: none"> <li>• Conduct preliminary assessment to understand context and needs of study or clinical population to determine device feasibility/acceptability and identify pragmatic barriers to adherence</li> <li>• Utilize a co-design approach to intervention development that employs a range of participatory methods to develop interventions that are feasible and acceptable to end-users.</li> <li>• Develop strategies to overcome identified barriers to wearable usage and adherence (e.g., providing smartphone, paying for data usage costs, avoiding devices that require a smartphone rather than a standard computer, setting up effective reminder systems, choosing a device with a longer battery life, etc.)</li> <li>• Ensure tracker is part of an engaging overall study approach</li> <li>• Providing external prompts or reminders to ensure compliance as needed</li> <li>• Provide clear instructions as to how much wear time is requested, the battery life, and the desired frequency of syncing</li> <li>• Check-in with patients and participants regularly to ensure they are not having any issues</li> <li>• For interventions, provide a phased approach to "unlocking" intervention features</li> <li>• Conduct research to determine the extent of reactivity to wearable devices and whether and how this reactivity dissipates according to the duration of the wear period (e.g., 1 week versus 1 month) or the use of repeated wear periods (1 week at three separate time points)</li> <li>• Work with device manufacturers, employers, insurers, and healthcare systems to create programs to provide financial assistance or free devices to all individuals or those who are unable to afford wearables</li> <li>• Determine which individuals are non-responsive and may need additional augmentation strategies, which augmentation strategies are most efficacious and cost-effective, and what the optimal timing is for delivering these augmentation strategies</li> </ul>
Device	<ul style="list-style-type: none"> <li>• Accuracy of PA assessment and intensity classification and inability to distinguish between postures (i.e., sitting, standing, lying)</li> <li>• Provision of clear, meaningful data that can be easily and accurately interpreted</li> </ul>	<ul style="list-style-type: none"> <li>• Conduct research to understand the accuracy of wearables in comparison to research-grade accelerometers using more rapid research designs</li> <li>• Include clinicians and patients in development of feedback associated with device</li> <li>• Conduct research to convert output data from wearable to public health</li> </ul>

Participant/Patient challenges	Challenges	Potential solutions/Future directions
	<ul style="list-style-type: none"> <li>Inequivalent metrics output by devices (most commonly) and public health recommendations for physical activity (minutes of moderate to vigorous intensity PA)</li> <li>Length of time required to conduct a traditional, rigorous validation study</li> <li>Rapid evolution of device design, features, user interface and software that is controlled by manufacturer</li> <li>Proprietary algorithms and limited access to raw data</li> <li>Features including durability, ease of use, battery life</li> <li>Cost</li> <li>Technology failures</li> </ul>	<ul style="list-style-type: none"> <li>recommendations or work with device manufacturers to refine output metrics to make them meaningful</li> <li>Coverage of device costs by insurer or employer</li> <li>Establish best practices for analyzing and storing data</li> </ul>
Clinical/Research setting	<ul style="list-style-type: none"> <li>Ease with which data can be aggregated and harmonized</li> <li>Development of effective and accurate algorithms</li> <li>Education of clinical team</li> <li>Integration with EHRs</li> <li>Actionable reports for clinical/research staff</li> <li>Efficacy/effectiveness of devices to change and maintain behavior without high level of oversight by research/clinical staff</li> </ul>	<ul style="list-style-type: none"> <li>Understand how to effectively integrate wearable data in EHRs so data are actionable by clinicians</li> <li>Establish best practices for combing wearable data with other data and for storing, processing, and analyzing these data</li> <li>Create standards for interpreting and processing data</li> <li>Determine how wearable data can be incorporated into clinic flow without creating unnecessary burden</li> <li>Develop educational materials and training to teach clinicians how to view, interpret, and act upon patient-generated data</li> <li>Develop staffing, reimbursement, and other structural support to facilitate usage of data</li> <li>Conduct interventions to assess the efficacy of device, alone, to change and maintain activity in patients with a variety of chronic conditions</li> </ul>

PA, physical activity; EHR, electronic health record

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