Spring 5-29-2020

Sensors and Wearables in Oncology: A study of the Barriers and Facilitators to Adoption

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Sensors and Wearables in Oncology: A study of the Barriers and Facilitators to Adoption

A Dissertation in Translational Health Sciences

By

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Submitted in Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy

May 29, 2020

Abstract

Innovation, although a subject of considerable debate (e.g., Baregheh et al., 2009; Christensen, 1997), can be defined as the introduction and dissemination of a new or a different idea into use or practice that drives impact (Solis and Sinfield, 2014). Many studies and editorials have highlighted the complexity of the United States health system and detailed the slow speed by which innovative ideas materialize into impactful innovations (Continuing America's leadership (2017); England & Stewart (2007); Kannampallil, Schauer, Cohen & Patel (2011)). While there are many advances in sensor and wearable technologies in this instance, the adoption rate by oncologists has been slow. This slow or lack of adoption has a deep impact on the care, comfort, and potential survival of cancer patients. This study intends to describe barriers and facilitators to sensor technology adoption in oncology, then map those barriers and facilitators across two sets of stakeholders (oncologists and technologists).

This qualitative study highlights key barriers including costs of technology, lack of time by oncologists, lack of communication between the two group, cultural and organizational factors, as well as global and policy factors. The enablers included the desire by both groups to work together for the benefit of the patients, as well as the need for tailored interventions leveraging an architected framework to propel this collaboration and align the stakeholders. The result of the study is a comprehensive conceptual framework and next steps detailed a short, medium, and long-term approach leading to adaptation, adoption, and diffusion. Being a first study of its kind, this can lead to further advancement in the field in terms of research and translational science.

Acknowledgement

I would like to thank my Chair, Dr. Leonard Friedman for his friendship, guidance, and mentorship, not just throughout this PhD journey but throughout the last ten years of patience, perseverance, and achievement. His words of encouragement, wisdom and good realistic attitude have guided me and allowed me to focus on the results. I would like to thank my committee members, Dr. Eduardo Sotomayor and Dr. Fernando Vidal-Vanaclocha for their time and dedication to the process, especially given their busy schedules. Their insights and guidance related to cancer care and innovation was invaluable. Finally, I would also like to thank Dr. Ayman Omar and Michael Benedict for their willingness to serve as "readers" of this dissertation and the value they bring to this experience.

I would not be able to do any of this without my personal support network. Beginning with my parents who have provided encouragement and have instilled a sense of drive in me to achieve. Their constant words of encouragement and support have been essential. I also would like to acknowledge "My Jessica" who has been so supportive, kind and patient as she listens to me talk through this dissertation topic and watches me navigate the process. Her support and cheerful attitude helped me tremendously and enabled me to drive to the finish line knowing that she has my back.

And finally, my reason for this journey; my children: Mia and Cooper. There has never been a more powerful driving force in my life. Since you were born, I knew that I had to be better. I know that your beautiful eyes will always be watching me and watching over me. You both made me realize that as a Dad, my first and most important role is to be an example for you and to show you that being hungry for knowledge and for learning is an essential way of life.

Thank you for being my “why.” Thank you for putting up with my long hours of studying, writing and class work. Thank you for being supportive and cheerful, and for being by my side throughout this journey. This is all for you so you can see that knowledge does not care what age you are. I hope that you see this as a small example of how to be a lifelong learner and how to take your rightful place in the world. I love you more than I can ever tell you or write about.

Title: Sensors and Cancer Care: The use and potential impact of wearable and sensor technologies and devices on cancer treatment

Chapter 1-A Overview.

Innovation, although a subject of considerable debate (e.g., Baregheh et al., 2009; Christensen, 1997), can be defined as the introduction and dissemination of a new or a different idea into use or practice that drives impact (Solis and Sinfield, 2014). Many studies and editorials have highlighted the complexity of the United States health system and detailed the slow speed by which innovative ideas materialize into impactful innovations (Continuing America's leadership (2017); England & Stewart (2007); Kannampallil, Schauer, Cohen & Patel (2011)). Concern about the lag in adopting new technologies and innovation has been brewing for some time. The healthcare industry is estimated to be ten or more years behind other industries such as financial services and transportation, in terms of leveraging the latest innovations related to sensor technology, data analytics and artificial intelligence (AI) for example (Kannampallil et al., 2011). This is specifically applicable in the field of Oncology as it relates to the adoption of new innovations such as wearable and sensor technologies. These technologies encompass many types of devices. For example, a person can wear a tracker to measure movement and pulse, implantable sensors to measure drug interactions or body vitals such as temperature, or ingestible sensors that measure drug interactions and can be controlled by a care provider.

While the broad industry, and Oncology specifically, is slowly waking up to the value of thinking differently and adopting new technologies, entrepreneurs in the wearable technology space face substantial challenges. These challenges stem from their lack of understanding of key

clinical issues and behavioral components exhibited by patients and oncologists in this highly complex health ecosystem (Continuing America's leadership (2017)). The consequences of a lack or a slow adoption is the inability to infuse these new technologies in cancer care, which could impact patients' lives and well-being.

Statement of the Problem.

The use of sensor technology has become an integral component of our lives and daily routine. We find sensors in our smart phones, wearable devices such as watches and blue tooth headsets, thermostats, and speakers. These sensors record and collect data about what we do and in return, provide tailored experiences and conveniences without much of a thought on our part. Sensor have found their way into medical practices, however, there remains a level of skepticism, distrust, and discomfort with the use of sensor technology in the oncology space. While there are many advances in sensor and wearable technology, the adoption rate by oncologists has been slow. This slow or lack of adoption has a deep impact on the care, comfort, and potential survival of cancer patients. This study intends to describe barriers and facilitators to sensor technology adoption in oncology, then map those barriers and facilitators across two sets of stakeholders (oncologists and technologists).

A good example of the continued focus on infusing technology and innovation (specifically wearables) can be found in the latest efforts by the National Cancer Institute (NCI) to encourage a conversation around cancer and the potential of wearable technology infusion. NCI has begun to create periodic conferences; bringing together scientists, medical informaticists, oncologists, molecular biologists, sensor and device technologists and manufacturers to discuss, plan and address the possibilities related to the intersection of wearable

technologies and cancer care. To that end, understanding the perceived barriers by patients, oncologists, and technology entrepreneurs to the adoption of wearable technologies for cancer treatment is essential to affecting the use of these innovative treatments by cancer patients. (Ries, 2011; Thaler & Sunstein, 2008)

Purpose and Research Questions.

This study will strive to understand the potential barriers to sensor technology adoption and the impact on usability by oncologists to treat cancer patients. These sensors may hold great promise in lessening the burden of cancer treatment and pain on patients and their loved ones and may even play an integral role in saving lives. To that end, the research questions aim to understand:

- **What are the perceived barriers and facilitators described by oncologists and technologists to adopting sensor technology for cancer treatment?**
- **How can adoption be enhanced?**

Statement of Potential Impact.

The use of sensors in oncology and the continued adoption of new and effective sensor technology in cancer treatment will provide a platform for future discoveries and advances for the benefit of patients. Using sensor technology, oncologists can provide tailored therapies coupled with continuous measurement for an optimal, effective, and efficient treatment.

Theoretical Foundation and Conceptual Framework.

Several frameworks, models and theories will be utilized to inform and frame the research methods. The Consolidated Framework for Implementation Research (CFIR) with its

focus on individual and contextual factors will be used to identify cognitive and behavioral factors that influence stakeholder behaviors. The Diffusion of Innovations Theory (Rogers, 1995) will be instrumental in defining the adaptation process and how innovations journey through the path from knowledge identification to adoption and evaluation.

Therefore, in terms of constructing a conceptual framework for this research, the Diffusion of Innovation Theory will serve as foundations to the identification of knowledge barriers and to translating that knowledge into action. The CFIR will serve to define the behavioral factors impacting stakeholder adoption and to inform any possible future intervention stemming out of this research.

Summary of the Methodology.

The research study will follow a qualitative approach. This study aims to:

1. Describe how oncologists and technologists regard wearable/sensor innovations related to cancer treatment. Through individual interviews conducted with 10 oncologists and 10 technologists, or until data saturation is reached, I plan to understand:
    - How do oncologists view, understand and approach new innovations related to cancer treatment?
    - For both oncologists and technologists, what are the barriers and facilitators that impact adoption
    - What do technologists need in terms of key knowledge and how do they obtain it in order to develop and facilitate the introduction of new innovative cancer treatment technologies?

- How does this knowledge of the barriers and facilitators advance the use of sensor and wearable technology in cancer care?

2. Conduct a thematic analysis of attitudes, barriers, and facilitators described by oncologists and technologists in reference to implementation (adoption and sustainability) of technology. The thematic analysis will draw on data from interviews.

Limitations and Delimitations.

This qualitative study could have some limitations stemming from the sample size and the demographics of those interviewed. The target participants represent oncologists and technologists; both are highly educated about the subject and have high expertise in their professions. Their views and resulting answers can bias the results based on information shared.

Definition of Key Terms.

There are no special terms requiring definitions.

Chapter 2-Purpose of the Study

Cancer is the second leading cause of death in the United States (Kochanek et al., 2016). Improved diagnosis and treatment options have translated into higher rates of cure and overall survival among those with cancer (Mueller et al., 2018). The use of sensor technology has become an integral component of our lives and daily routine. We find sensors in our smart phones, wearable devices such as watches and blue tooth headsets, thermostats, and speakers. These sensors record and collect data about what we do and in return, provide tailored experiences and conveniences without much of a thought on our part. Sensor have found their way into medical practices, however, there remains a level of skepticism, distrust, and discomfort with the use of sensor technology in the oncology space. While there are many advances in sensor and wearable technology, the adoption rate by oncologists has been slow. This slow or lack of adoption has a deep impact on the care, comfort, and potential survival of cancer patients. This study intends to describe barriers and facilitators to sensor technology adoption in oncology, then map those barriers and facilitators across two sets of stakeholders (oncologists and technologists). Specifically, the research questions are:

- **What are the perceived barriers and facilitators described by oncologists and technologists to adopting sensor technology for cancer treatment?**
- **How can adoption be enhanced?**

Research Approach

Based on these questions, key concepts and keywords began to be identified. Research librarians were consulted to verify the approach and to seek guidance on suggested search terms and approaches. Key terms that the search commenced with included “Health Innovation,”

"Wearable Technology," "Innovation," "Oncology," "Entrepreneurship," and "Design Thinking." The term "innov" was also used to account for possible notations of the concept (innovation vs innovate vs invention). Similarly, the term "wearable" was used to account for possible delineations (wearable devices vs. wearable technology vs wearables). These terms were researched in various databases including PubMed, CINAHL, Scopus, Clinical Key, Health Affairs, Google Scholar, and several other gray literature collections such as Harvard Business Review (HBR) and various blogs. The research was limited to publications in the past 10 years (2008-2018) in order to account for new technological innovation in the field of wearable technologies in addition to focus on recent advances in oncology care using technology.

Key domains from the research included:

- Leadership
- Teams
- Health Services
- Oncology / Cancer
- Wearable Devices
- Learning
- Entrepreneurship
- Management
- Technology
- Innovation
- Design Thinking

Below are two small examples of the research performed in two of the databases mentioned. Please note this process was iterative and comprehensive, and the below is only shown as an example, and is not meant to be a comprehensive search example for replication purposes.

PubMed:

(Health Innovation [Mesh] OR Innovation* [tiab] OR Innovation [mesh] AND Entrepreneurship [tiab])

(Wearables [mesh] OR Wearable Technology [tiab] OR Wearable Technology [mesh] OR Wearable Devices [tiab])

SCOPUS:

TITLE-ABS-KEY ("Health Innovation" AND "Entrepreneurship")

Given the broad nature of the topic of innovation, the initial search returned 32,274 publications from all the databases utilized. This was further refined by limiting the date to the past ten (10) years, which returned 18,505 entries. Upon removal of duplicates and further refining the search terms using MeSH searching in PubMed, using “health” AND other terms such as oncology and wearables, and several other iterations, a smaller more focused number of entries totaling 6,467 was obtained. The area that generated the most literature was Design Thinking and Entrepreneurship at 3,226 entries. The second focus area in terms of search result was Oncology. Several exemplar articles were utilized for further research and to obtain additional keywords. These exemplar articles were of high level and discussed the concept broadly. This led to further refinement of the literature search and to break down Health Innovation, for example, into several components.

This systematic process included reviewing the title of every publication to determine its relevance. A filing protocol was developed to track the publications. For titles that were deemed relevant, a process of abstract and conclusion review was performed to further narrow down the number of articles to those that came close to the topic at hand. Through this assessment of the abstracts, continuous literature review of articles, studies and reviews, different domains and stakeholder were identified for inclusion. Care was given to not judge the "quality" of the study, rather the literature in its broadest perspective and how it related to the concept at hand. Additional care was given to searching for and obtaining a representative sample of studies that focused on both qualitative and quantitative aspects of the topic. In doing so, certain studies and articles stood out as providing the most comprehensive view of the topic of oncology patient care using technology. While the search began with numerous results, narrowing down the field of healthcare to target only Oncology, along with narrowing down the field of innovation to focus on wearable devices and technology was helpful at arriving at a focused literature review. Additionally, narrowing down the list of stakeholders to only patients, oncologist and technologies aided in further refining this list. This resulted in 35 studies that were a part of this assessment. These 35 publications provide a diverse yet comprehensive view on the subject and provide the reader with a sound foundation or a baseline to further understand the topic under study.

Description and Critique of Scholarly Literature

Cancer is the second leading cause of death in the United States (Kochanek et al., 2016). Improved diagnosis and treatment options have translated into higher rates of cure and overall survival among those with cancer (Mueller et al., 2018). Individuals with cancer frequently require administration of oral chemotherapy or symptom management medication at home,

which places significant amount of pressure on caregivers, and on care providers who often have difficulty managing the patient care once the patient leaves the hospital or clinic (Mueller et al., 2018). The use of technology has provided additional options for both caregivers and care providers. These technologies often referred to as wearables, sensors or mobile health are beginning to play a critical role in cancer care. The use of mobile health (mHealth), defined by the national institute of health consensus group on mHealth as the use of mobile and wireless devices to improve health outcomes, healthcare services and health research , has grown exponentially in recent years (Pew Research Center, 2018). Such technologies have the potential to assist care providers as they navigate complex diagnosis and direct the medical management of their patients. Given the serious implications to these sensor and wearable technology, it is imperative to understand the usage of this technology as well as barriers and desires of those that interact with it.

The field of research related to barriers and facilitators to the adoption of sensor technology is very limited. Various level of searches as indicated above have resulted in limited literature. This lack of literature about the subject was confirmed through conversations with several key researchers at the National Institutes of Health (NIH) and the National Cancer Institute (NCI). This field is evolving rapidly, and the content and research is new. Therefore, there is limited relevant research in this subject.

Due to the limited research in this area, it was critical to expand the search to look for themes and studies where similar situations and issues are noted. These themes and other relevant content are described below in separate sections.

Adoption of technology in healthcare

Clinicians, and specifically physicians, face several factors that influence their view of technological innovations in medicine. In a systematic review study conducted by Luckett et al. (2013) to assesses factors and develop insights around comprehensive patient care, several factors influencing the adoption of technology by doctors were identified. These factors include professional contexts, influences, professional norms, performance incentives and targets, accreditation, government policy and organizational initiatives (Luckett et al., 2013). Additionally, individual factors impacting doctor's perception include attitudes, values, knowledge, personality, gender, age, ethnicity, and knowledge of the patient (Luckett et al., 2013). In this study, health care professionals admit that their own personal experiences influence their approach to treating patients with chronic conditions. They also confirm that their perception of the patient, as well as their own needs, dictate their adoption rates of new technologies (Luckett et al., 2013). The study also cited the lack of time experienced by healthcare professionals in playing a large factor in the lack of adoption and use of technology such as sensors and wearables. Clinicians often complain that they barely have time to see their patients and do not have the availability to learn something new. That said, in one instance, a group of oncologists indicated that they expect that patient care, and especially pain should be manageable and felt that they would let the patient down if they do not seek innovative ways to manage their pain. This also served as a catalyst for further use of the technology since the clinicians felt a sense of satisfaction out of managing their patients' pain (Luckett et al., 2013).

In the same study, oncologists were skeptical of the use of traditional and formal pain assessments and they felt that new innovative technologies and sensors measuring pain and dosage information could be beneficial and more efficient. That said their focus was primarily on pharmacological strategies and how sensors and wearables can measure drug interactions and

effect of the patient (Luckett et al., 2013). Oncologists championed the use of certain ways of measuring and treating cancer care and expressed the need to have assistive technologies to help them manage patient care and to provide guidance and audit mechanism to their efforts. They placed a high priority on teamwork and communication between themselves and technologists (Luckett et al., 2013). One of the barriers indicated by these oncologists was that hierarchy in the health system was a negative influence for teamwork and on the adoption of new technologies. Ridged roles were perceived to hamper the adoption of these new technologies (Luckett et al., 2013).

Broadly speaking, factors influencing the adoption of innovative therapeutic processes included the duration and approximate time to gain knowledge by the practicing clinician, the ease of understanding the technical jargon, and the overall knowledge and understanding of the relative impact of the new innovation on the patient treatment and outcomes (Popper-Giveron et al., 2014)

Barriers and Facilitators to innovation implementation

In a study conducted by Moloczij et al. (2017), several barriers and facilitators to the adoption of various assessment methods in oncology were noted by patients and their care providers. For example, some patients rejected the use of questionnaires for fear that it will reduce the amount of time they get to spend with their oncologists (Moloczij, 2017). They feared that by answering questionnaires ahead of time, the content of their interaction with their oncologist will not be of the same level of quality as those who spent time with the oncologist discussing some of these similar questions. There was also a fear of a breakdown in the level of relationship between the oncologist and the patients. Participants in the study, especially

oncologists and clinicians, identified several benefits for patients and additional benefits to the clinical staff (Moloczij, 2017). These benefits include additional time, a more efficient and effective encounter, and better information. Despite the potential benefits of these communication strategies there were some important individual, system and medical legal barriers which would need further consideration before implementation into routine practice (Moloczij, 2017).

User Centered Design

For technological innovations to take shape and be adopted, user centeredness, specifically oncologist user centeredness in this case is critically important. This user centeredness and realism in the design, implementation, an evaluation of new methods of health care delivery and treatment of cancer patients leveraging wearables and sensors, is critically important (May, 2015). It is important to consider the meso level dynamics that shape these new innovative technologies and processes. Ideas about demand, choices about services, expectations of oncologists and their patient needs, and requirements of health care workers all form as set of moral and political assumptions that are frequently left outside the debates regarding provider empowerment through new healthcare technological systems (May, 2015).

How Sensor Technology is applied aid the aging population

As the population in the United States ages and incidents of cancer continue to increase, there needs to be compliments to traditional assessments and oncology care. The implementation of health technology on a broader scale requires doctors, patients, and technology innovators to think differently and to develop new innovations outside of routine medical care (Shen & Naeim, 2017). Though the commercial and recreational use of new technology has increased, the

transition into creating a smart and connected home that can interface with both patients and healthcare professionals is still slow (Shen & Naeim, 2017). Current limitations cited by oncologists in this study include awareness of the digital divide their patients experience, concerns regarding privacy and security, data volume, rapid change, cost, and reimbursement. According to Shen & Naeim (2017), the emergence of low cost, high fidelity wearable sensors with a spectrum of clinical utility may be the key to increased use and adaptation for these cancer patients. An opportunity to utilize wearable sensors for objective and real time assessment of patients with cancer for baseline functional status and treatment toxicity may be on the horizon.

Sensors have been used in healthcare for several decades, Starting with inertial sensors that could perform automated mobility assessment such as the timed up and go test (TUG) in order to stratify patients with frailty criteria, or to construct clinically relevant algorithms applicable to diagnostic work up or long-term monitoring (Green et al., 2014). Wearable sensors allow for objective and discriminative assessment of physical function during activities such as gate or position change (Shen & Naeim, 2017).

The ability for data from wearable sensors to be utilized by machines and machine learning models to distinguish functional upper extremity use from ambient or movement also provides an important level of detection (Green et al., 2014). Given the frequency, morbidity and mortality related to falls in the geriatric population, there have been many studies utilizing wearable sensors to quantify limb movement and gait, and to compare these metrics with outcome data (Marschollek et al., 2011). In other populations of geriatric patients with dementia, sensor-derived physical activity data was found to be in dependently predictive of fall risk and may have had high diagnostic accuracy compared to conventional forest measures (Schwenk et al., 2014). The next logical step in their utilization is formulating protocols for fall risk

assessments and identification that can be rapidly relate to health care providers and allow for timely interventions (Shen & Naeim, 2017). Wearable sensors are now developing the ability to capture individual physiological data such as vital signs, posture, movement, localization, and sleep patterns. Collecting an expansive volume of daily information from an individual can generate unique baselines and help detect personal differences in physiologic parameters which may be suggestive of early disease process or treatment outcomes (Shen & Naeim, 2017).

There are ongoing studies in chronic diseases such as diabetes and Parkinson's disease that suggest the benefit of the use of commercially available wearable sensors to monitor physical activity and correlate such data with various outcome measures such as adverse events, health care utilization and quality of life surveys. Many of these studies support the use of wearable sensors in these chronic conditions.

The Smart Home

A smart and connected home is one that includes one or more devices that are connected to the Internet and can be controlled through applications on a smartphone, smartwatch, tablet, or smart TV. There are many benefits of the smart connected home and remote monitoring. First, it can improve care access for patients in rural less populated areas and patience with barriers to transportation. Furthermore, when used across a population, it can help risk stratify patients to identify at risk patients who require prompt medical attention. These systems can also be used to send immediate health alerts or notifications if an abrupt change is detected.

As newer technology such as wearable sensors afford the opportunity to collect additional in-home predictive metrics, it will be valuable to determine if and how patient data can augment or improve upon traditional assessments. For any technology to be successful, it requires a deep

level of standardization and integration (Shen & Naeim, 2017). This technological and data maturing can be combined with clinical studies to elucidate the potential for population-based risk stratification than interventions that target improve the care of older patients with cancer (Shen & Naeim, 2017).

Sensor Use for Dehydration Monitoring in Radiation patients

In a study by Peterson et al. (2013) researches tested at home sensors to alert doctors to dehydration risk in radiation patients. The patient uses sensing devices at home and on the go. The sensors collected blood pressure, pulse, and weight data. Data is then sent to a hub which gathers the data from these sensors and transmits them to a centralized system where oncologists are able to monitor the effect of radiation on cancer patients and monitor their dehydration risk (Peterson et al., 2013). The patient, through a mobile app, are also able to answer questions related to symptoms of dehydration. When these symptoms appear worrisome to the oncologists, the system flags the condition so that the clinician's attention will be drawn to it. The clinician then evaluated the findings and, in some cases, called the patient or had them come in for intravenous fluids (Peterson et al., 2013). This system, outlined in the study, may allow for early detection of patients who have become dehydrated and could have a real potential for changing outcomes and avoiding hospitalization and acute complications.

Sensor Use to Manage Cancer’s ability to spread

In a study conducted by Bhandari et al (2015), the research team used novel engineered biosensors and sophisticated microscopes to monitor the modification on a Gα-interacting vesicle associated protein (GIV) and found that Florissant signals reflected a tumor cell meta static tendency. They were then able to measure the metastatic potential of single cancer cells and

account for the unknown of an evolving tumor biology through this activity (Bhandari et al., 2015). The result was the development of fluorescence resonance energy transfer biosensors. This kind of imaging can be used for developing treatment to see how individual cells are responding in cancer patients. While these sensors continue to need further refinement, they have the potential to be a transformative advance for cancer cell biology (Bhandari et al., 2015)

Optical Biosensors in Oncology

Using molecular tests in oncology has significantly improved clinical practices. Dosage of molecules from body fluids allow early detection, treatment tailoring and prognosis prediction (Donzella & Crea, 2011). These tests are mainly based on the identification of specific proteins, or genetic alterations. Despite this, cancer prognosis remains dismal in many cases, and clinical outcomes are often unpredictable (Recchardi et al., 2010). In addition, treatment tailoring based on molecular profiling is still a challenge. The main obstacles to overcome are the complex nature of molecular alterations occurring in cancer patients as well as the accessibility of tumor derived biological samples (Donzella & Crea, 2011).

Laboratories on a chip (LOCs) can dramatically improve analysis tools available for oncologists, in terms of high degree of analysis parallelization (Donzella & Crea, 2011). They can integrate and automate all needed sample process functionalities into an inexpensive, portable, and disposable thumb sized device. The use of sensors in this matter can substantially improve the accuracy of diagnosis and the possibility of a better treatment outcome for cancer patients. The term LOC Has been used to identify devices in which microelectronic, photonic, and microfluidic structure are integrated together to perform biological analysis (Donzella & Crea, 2011).

Whole-genome epigenetic profiling will be a goal of 21st century by medical research. In this context, the identification of cancer specific histone modifications will be possible (Donzella & Crea, 2011). Since cancer is a multigenic disease, each cancer type could be likely identified by several histone modifications. The use of LOCs can provide several advantages. These advantages can be broken out into three different categories. One is the identification of markers of cancer initiation for early diagnosis. Two, is the identification of prognostic or predictive markers, to tailor treatment decision. Three, is the analysis of easily accessible biological fluids such as blood samples but also to more specific fluids (Donzella & Crea, 2011). Despite these advantages and promising applications some drawbacks need to be overcome. Some technology issues should be solved, namely finding the suitable materials which can be used not only for integrating optics fluidics in electronics but also to guarantee biocompatibility (Recchardi et al., 2010). Devices should be optimized through proper engineering to improve performance, sensitivity, detection limit, and analysis time with respect to current available techniques (Recchardi et al., 2010). Finally, appropriate trial should be designed to validate LOC effectiveness in specific clinical settings. This is an on-going effort to ensure efficacy and effectiveness (Recchardi et al., 2010).

Nano Pharmacology

Nano-pharmacology is an interdisciplinary research field, which was developed as an interaction between chemistry, engineering, biology, and medicine, and it is currently receiving growing interest in the clinics (Tomuleasa et al., 2014). Progress in nanotechnology has gained attention in recent years by developing novel nanoparticle-based drugs or by discovering novel applications in early diagnostic or prognostic essays in cancer (Tomuleasa et al., 2014). The latest advances in nanotechnology have brought various options that could be used in the clinic

by empowering constructs for molecular diagnosis, disease detection, cytostatic drug delivery and nanoscale immunotherapy (Rotello, 2009).

In cancer chemotherapy, the mission is to achieve a good therapeutic index, which is the ratio of the lethal dose for 50% of the population to the minimum effective dose for 50% of the population (Tomuleasa et al., 2014). However, cancer is most often characterized by multi-drug resistance (MDR) and the scientists have developed a new way to target these cells. Multi-drug resistance cells are known to be frequently located in hypoxic areas, distant from any blood supply, thus overcoming the natural barrier of drug efflux pump activity (Tomuleasa et al., 2014). Designing smart molecules using sensors or the construction of nanoparticles can aid in delivering the medication to these remote regions where the multi- rug resistant cells are located.

In recent years, important progress has been made in nanotechnology, with its ever-increasing applicability in basic and translational medicine, leading to the appearance of a new field known as nanomedicine (Tomuleasa et al., 2014). This new science deals with the engineering of various structures of nanoscale dimensions that can be properly conjugated with various highly specific targeting agents in order to be used in the clinic, for either early diagnostic purposes or for disease treatment (Tomuleasa et al., 2014). These steps in clinical oncology however are still far from being implemented in clinical practice (Tomuleasa et al., 2014). Nevertheless, with each passing innovation we come closer and closer to a patient tailored approach in order to achieve maximum anti-cancer effects with minimal side effects (Tomuleasa et al., 2014).

Chemotherapy induced peripheral neuropathy (CIPN)

With the increase in the number of cancer cases affecting adult patients, there is increased potential for serious side effects stemming from cancer related treatment (Zahiri et al., 2019). While chemotherapy is used to treat cancer by destroying malignant cells, it can also cause severe damage to noncancerous cells causing a deterioration in the gait and balance ability of patients. This deterioration is due to chemotherapy induced peripheral neuropathy (CIPN) (Zahiri et al., 2019). According to a study by Tofthagen, C., patient suffering from CIPN had a sever reduction in the quality of life experience which in several cases caused difficulty to cope more than the cancer itself (2010).

Hung et al., in a study published in 2017, describe the use of wearable sensors such as inertial measurement units to measure physical activities for patients suffering from movement disorders such as Parkinsons' disease. The evaluation of these movements can also be applied to cancer patient suffering from CIPN. Utilizing sensors and wearable technology could lead to faster evaluation of the quality of movements and aid in addressing these concerns through medical treatment including physical rehabilitation (Hung et al., 2017).

Inference for Forthcoming Study

As discussed in the preview section, sensor technology and smart devices are all around us and continue to play increasingly important roles in our lives. Technological advances in sensor technology and wearables have found their way into the medical field and have been leveraged to support care in chronic conditions such as diabetes and Parkinson's disease. Cancer is the second leading cause of death after heart disease (Kochanek et al., 2016). Potential innovations and uses of such technology can have a profound impact on the care management and eventual hopeful survival of cancer patients.

While sensor technology has found uses in other chronic conditions, oncology care has been slow to adopt such innovations. There are pockets of innovative uses in the nano pharmacology space or the molecular space. These advances have not found their way into the mainstream oncology treatment. The lack of adoption of these technologies can have adverse effects on patients and could contribute to lives lost.

In order to understand and enhance the adoption of sensor technology in oncology, we must first understand the perceived barriers and facilitators to adoption. In prior studies, clinicians point to various barriers and facilitators. Some of these are individual and some are contextual. Based on the literature review, research has not focused on the perceived barriers and facilitators to adopting sensors and wearables in oncology. Furthermore, the technologists have been left out of the process, even though they play a pivotal role in translating knowledge of sensor technology into actionable solutions for treatment. Therefore, the stakeholders and key participants of this study are oncologists and technologists.

Upon understanding and describing these barriers and facilitators to adoption by oncologists and technologists, it is imperative that we can take the themes and knowledge gained and convert it into an actionable plan that address is the strategies to increase adoption. Leveraging various conceptual framework to inform and influence the data gather and analysis, will allow us to have a comprehensive view of these results and to translate the knowledge into action.

Theoretical or Conceptual Framework

Two key frameworks and theories will be utilized to inform and frame the research methods. The Consolidated Framework for Implementation Research (CFIR) with its focus on

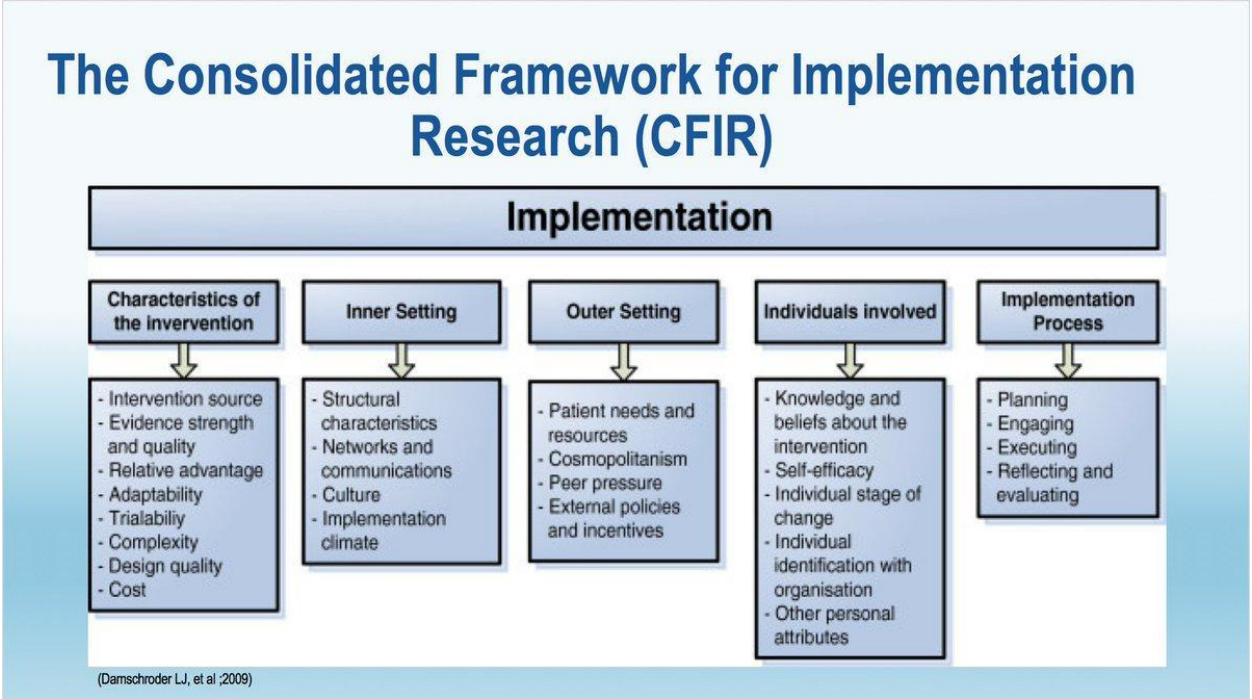
individual and contextual factors will be used to identify cognitive and behavioral factors that influence stakeholder behaviors. The Diffusion of Innovations Theory (Rogers, 1995) will be instrumental in defining the adaptation process and how innovations journey through the path from knowledge identification to adoption and evaluation.

The Consolidated Framework for Implementation Research

In 2009, Damschroder et al. reviewed and synthesized several implementation science theories into what has become the Consolidated Framework for Implementation Research (CFIR) (Kirk, et al., 2016). The common language provided by CFIR allows for a holistic view of the barrier and facilitators influencing the adoption and implementation of change. According to Kirk et al. (2016) "CFIR is comprised of 39 constructs across five domains that interact and influence implementation effectiveness." (3)

According to Klafke et al. (2017), CFIR's five domains include the intervention characteristics such as adaptability, cost and complexity, the outer setting addresses resources, needs and regulations, the inner setting includes information on structure and the readiness for change, the individual characteristics provide a better understanding of the individual knowledge, self-efficacy and the decision making process, and the implementation process domain addresses communication between the individual and organization and the feedback process (Klafke et al., 2017). Only specific components and domains will be utilized for the purpose of this research in order to focus the work on what is relevant to the identification of the barrier and facilitators impacting the adoption of sensors in oncology.

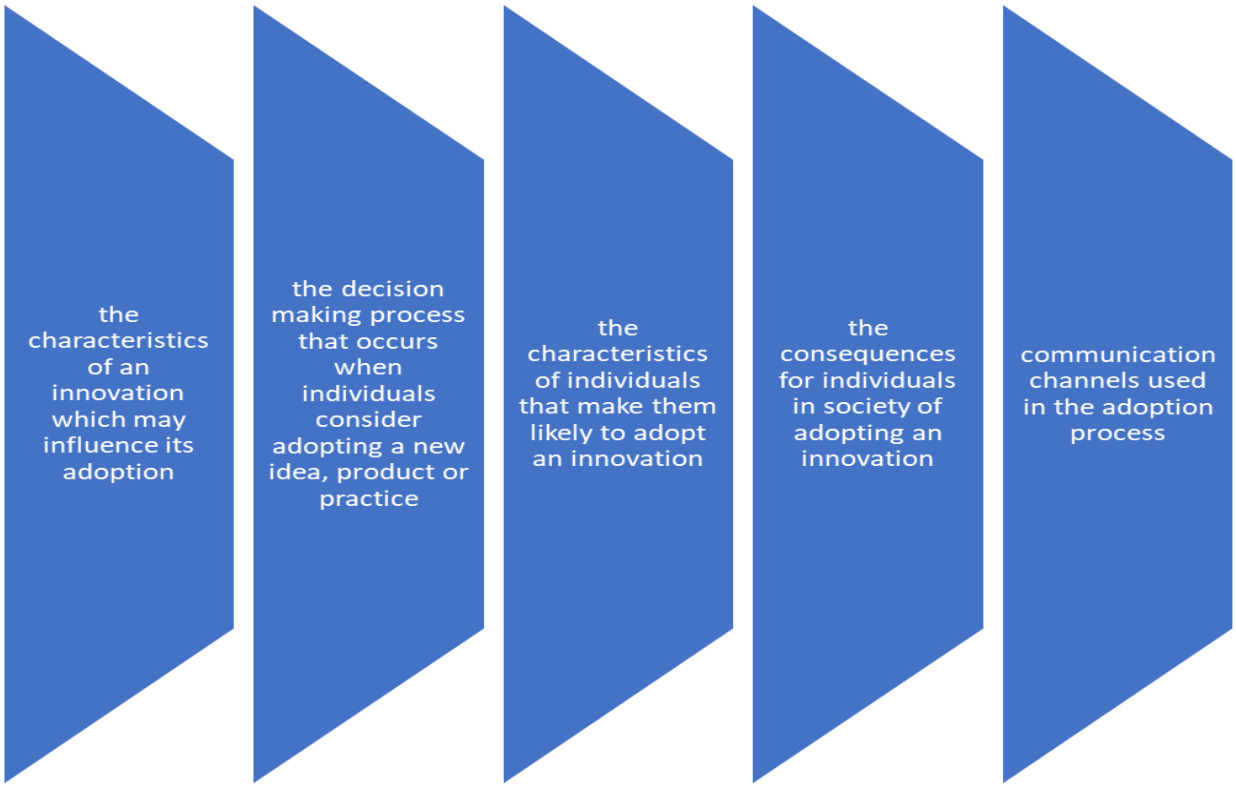
Figure 1 – The Consolidated Framework for Implementation Research (CFIR)



The Diffusion of Innovation Theory

Rogers argues that "diffusion is the process by which an innovation is communicated overtime among the participants in the social system" (Rogers, 1995). Adoption is a decision of full use of an innovation as the best course of action available and rejection is a decision not to adopt an innovation. Diffusion has focused on 5 areas as depicted in Figure 2:

Figure 2 – The Focus of Diffusion (Rogers, 1995)



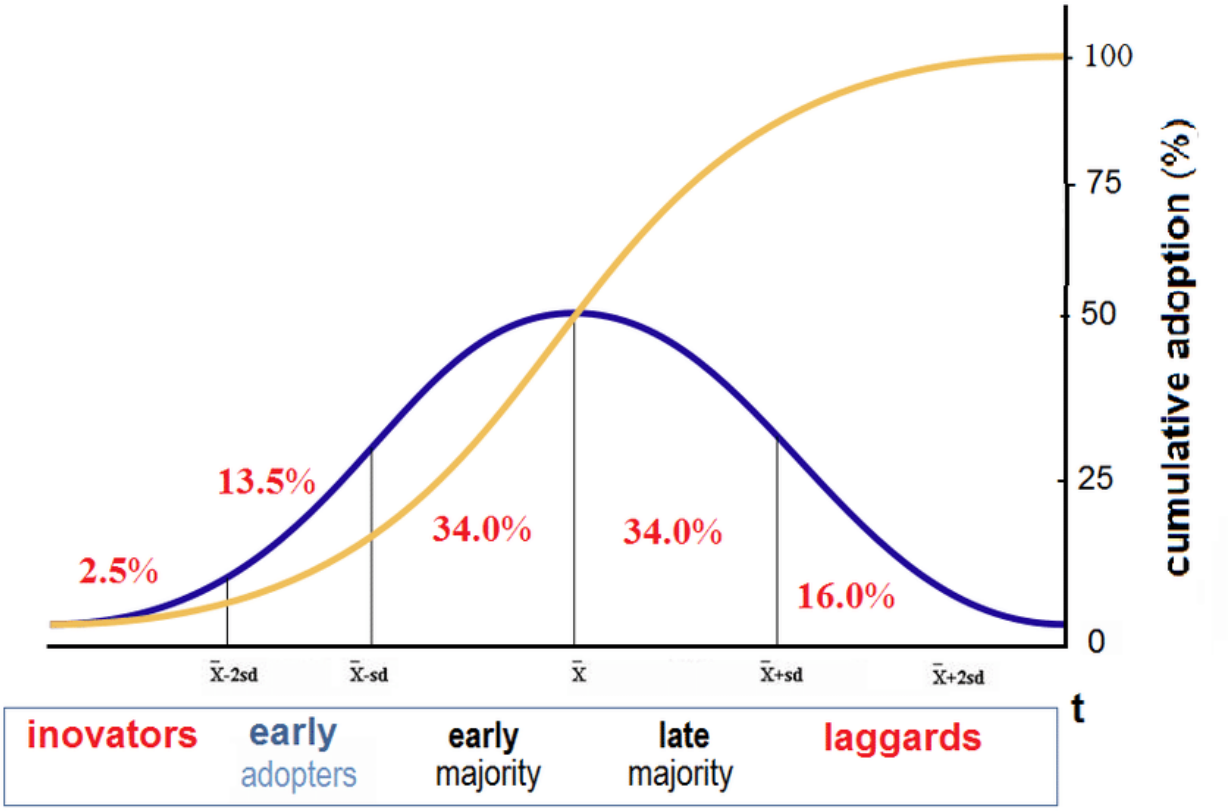
Given the above, Rogers proposes 4 main elements that influence the spread of a new idea. These elements include the social system, the time of the innovation, the various communication channels, and the said innovation (Rogers, 1995). With any new change, certain individual sway more influence than others in determining the trajectory or success of an innovation. These influencers, or as Rogers calls them “Opinion Leaders”, can impact user behavior via their personal contacts and role.

An innovation is an idea, a practice or an object that is perceived to be new by an individual or other unit of adoption (Rogers, 1995). For diffusion to occur Rogers discuses five stages or steps. These are awareness, interest, evaluation, trial, and adoption our integral to this theory (1995).

According to Rogers (1995), in order for the innovation process to commence and for a decision to be made to adopt the innovation the individual must go through several steps. The first step is knowledge and awareness. The second step is persuasion. At this stage, social networks and influencers play a pivotal role. The third and critical stage is the decision-making process. Rogers contents that this is a difficult stage due to the lack of proper empirical evidence to allow the person to make the decision (Rogers, 1995). Once a decision has been made by the individual, implementation begins. This is where innovation usefulness is measured and evaluated. The final stage is confirmation. At this stage, individuals determine whether to continue using the innovation or not. (Rogers, 1995).

The rate of adoption is defined by Rogers (1995) as the relative speed at which participants adopted innovation. There are several categories related to the type of adopters as outlined by Rogers. He defines these categories as innovators, early adopters, early majority, late majority, and laggards (Rogers, 1995).

Figure 3 – The Diffusion of Innovation Theory (Rogers, 1995)



The social system constructed around an innovation plays a pivotal role in its adoption (Rogers, 1995). Opinion leaders for example, those who are well respected or of higher authority, are critical to the success and sustainability of an innovation. They have great exposure and extensive contacts enabling stronger dissemination of information. Another critical influencer to the adoption of innovations are the organizations themselves. Innovations are often adopted by organizations through two types of innovation decisions. Collective innovation decisions and authority innovation decisions (Rogers, 1995).

Diffusion is a social process that occurs among people in response to learning about an innovation such as a new evidence-based approach for extending or improving healthcare. Dissemination activity and diffusion processes are wholly distinct. Dissemination refers to activities by proponents or intermediaries to inform others of an innovation, often in terms of

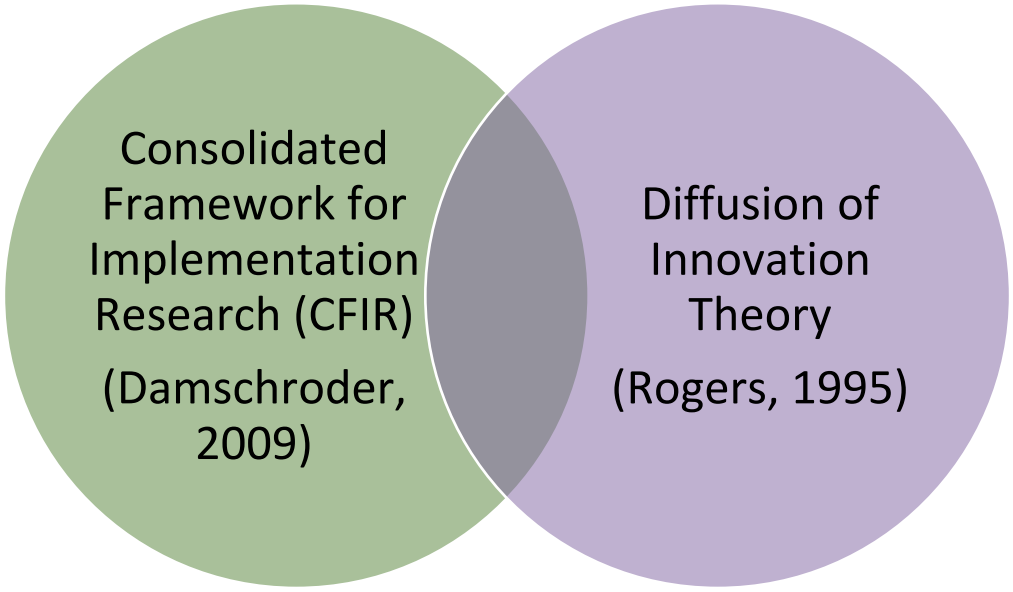
segmenting targeted audiences. Information about an innovation is transmitted or advertised usually in one-to- many process using social, mass, or specialty media channels, though simply making information available is probably more common (Rogers, 1995). So, diffusion is a form of social activation that may or may not occur after the dissemination of information or scaling up or service or products has occurred. Diffusion can also occur without organized, intentional dissemination. Rogers defines an implementer as someone who will change their behavior to use an innovation in practice (Rogers, 1995). In complex organizations, the users are often not the choosers of an innovation. Historically, little attention to implementation has been a major limitation of diffusion. Policy diffusion researchers have found that beliefs about and innovations effectiveness can be more important than knowledge of an actual outcomes, again suggesting that who has previously adopted innovation can be more important for decision makers than what was previously adopted and what effect it has.

In terms of fidelity, Rogers defines it as the extent to which innovation is implemented by others in the way intended by its developers. Fidelity can be affected in the process of diffusion in two ways: reinvention and adaptation. Reinvention refers to changes made by and innovations developer turn innovation before his disseminated. Adaptation refers to changes made to an innovation by implementers who serve intended beneficiaries. Adaptations are made by staff in response both to the immediate context of a health care or public health organization setting and to changes in the external environment that can make or break the sustained applicability of an innovation for improving health and healthcare.

Therefore, in terms of constructing a conceptual framework for this research, the Diffusion of Innovation Theory will serve as foundations to the identification of knowledge barriers and to translating that knowledge into action. The CFIR will serve to define the

behavioral factors impacting stakeholder adoption and to inform any possible future intervention stemming out of this research. Certain components of each of these frameworks will be selected to advance the knowledge and guide this research. From CFIR, the Inner, Outer, and Individual domains will be utilized to provide a holistic view of the process impacting adoption. In the Diffusion of Innovation Theory, the focus will be on the decision-making process, individual characteristics, and communication. Ultimately, CFIR and the Diffusion of Innovation Theory will, together, provide a roadmap guiding this research, aligning the questions asked of participants and categorizing the responses in sense making process that is conducive to further action.

Figure 4 – A combined approach to the Conceptual Framework

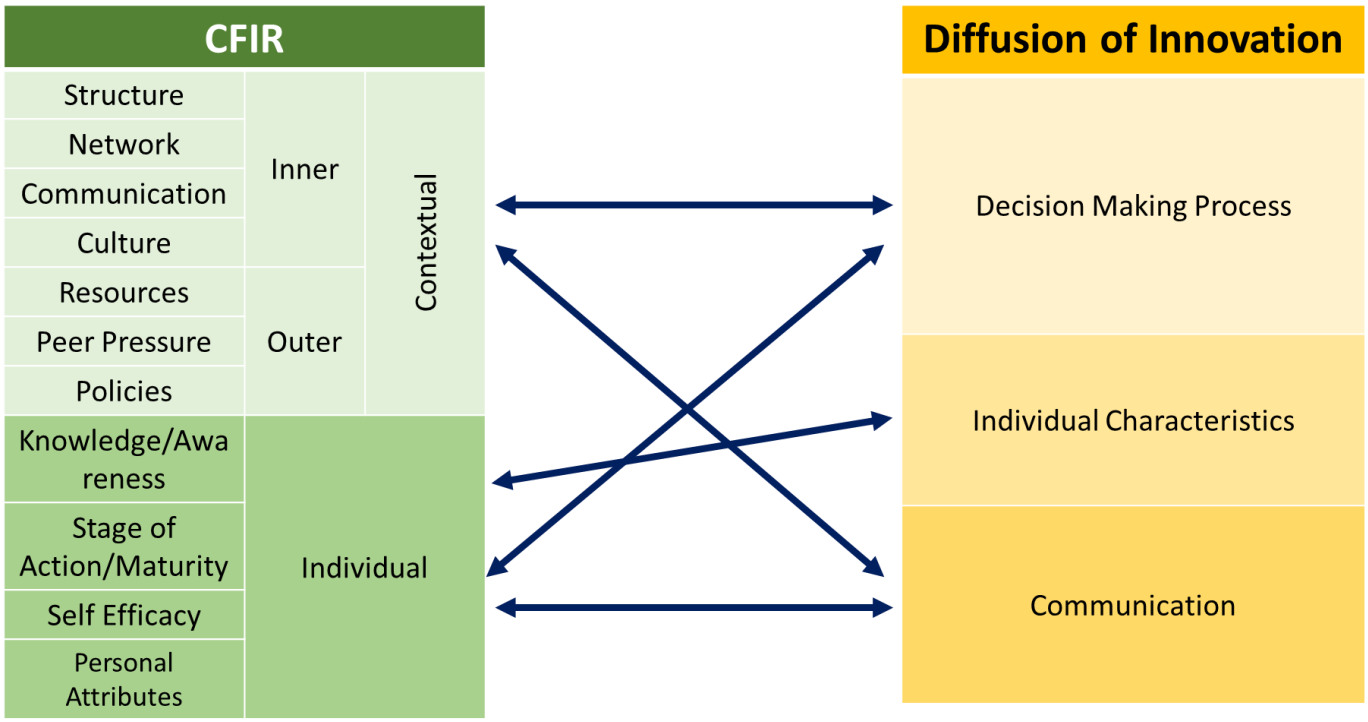


A Combined Conceptual Framework

The combination of these two frameworks allows us to select key domains, attributes, and focus areas to guide this research. As noted in Figure 5, there is tremendous synergy between

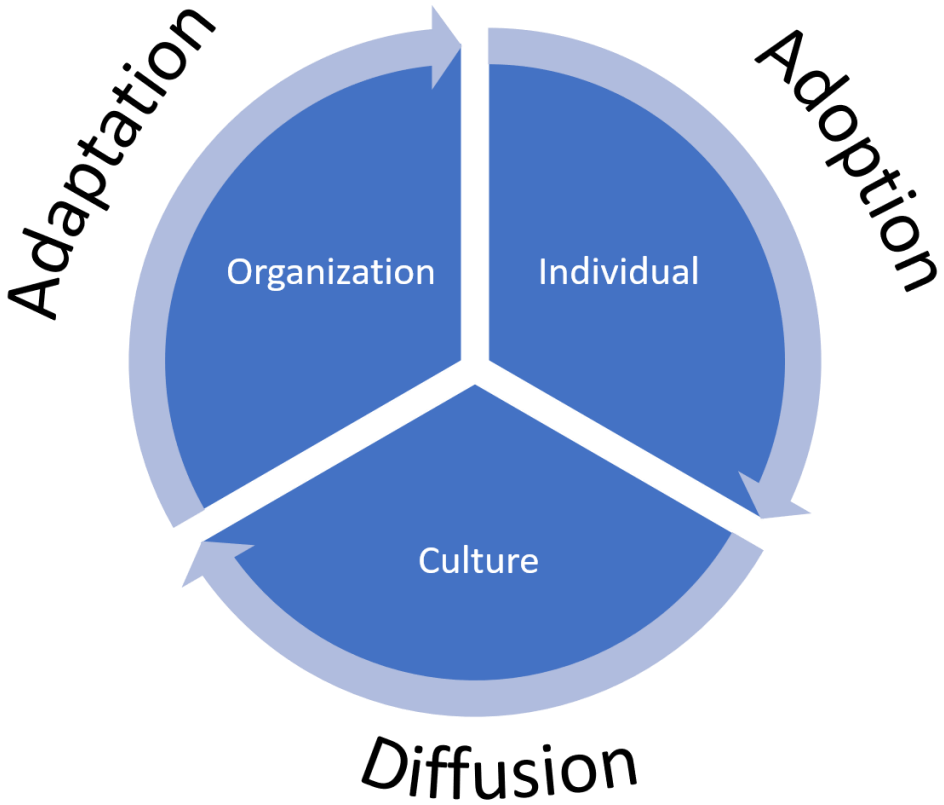
CFIR and the Diffusion of Innovation Theory in that they complement each other and drive the researcher to the key attributes, barrier and facilitators influencing adaptation, adoption, and diffusion.

Figure 5 – A combined conceptual framework analysis adapted from CFIR (Damschroder, 2009) and Diffusion of Innovation (Rogers, 1995)



The resulting conceptual framework stemming from this combination informs the research and focuses it on the organizational, individual, and cultural attributes driving adaptation, adoption, and diffusion. This new conceptual framework is depicted in Figure 6.

Figure 6 – Conceptual Framework guiding this research study


Adaptation
Adoption
Organization
Individual
Culture
Diffusion

Chapter 3 - Overview of the Methodology

This study intends to describe barriers and facilitators to sensor technology adoption in oncology, then map those barriers and facilitators across two sets of stakeholders (oncologists and technologists). Specifically, the research questions are:

- **What are the perceived barriers and facilitators described by oncologists and technologists to adopting sensor technology for cancer treatment?**
- **How can adoption be enhanced?**

Research Procedures & Participant Sampling

The research study follows a qualitative approach. This study aims to assess how oncologists and technologists regard wearable/sensor innovations related to cancer treatment. Purposeful sampling was employed in order to create two groups of participants: oncologists and technologists. A snowball sampling technique was used to identify and obtain participation from the study subjects. This snowball sampling method relied on reaching out to initial participants and they in turn recommended others for the study. The researcher then contacted the individuals recommended for interviews until the sample arrived at the expected size of 10 oncologists and 10 technologists. These interviews of the 10 oncologists and 10 technologists aimed to understand:

- How do oncologists view, understand and approach new innovations related to cancer treatment?
- For both oncologists and technologists, what are the barriers and facilitators that impact adoption

- What do technologists need in terms of key knowledge and how do they obtain it in order to develop and facilitate the introduction of new innovative cancer treatment technologies?
- How does this knowledge of the barriers and facilitators advance the use of sensor and wearable technology in cancer care?

A thematic analysis of attitudes, barriers, and facilitators described by oncologists and technologists in reference to implementation (adoption and sustainability) of technology was conducted. The thematic analysis drew on data from interviews and based on a coding approach that looked for consistency and key discussion points to arrive at the key themes. The results of this study provided guidance on how to better enhance the adoption of sensor and wearable technology in cancer care, and how to advance this field.

Institutional Review Board (IRB) approval for this study was obtained before commencing engagement with the participants. Qualitatively, data was collected through semi-structured individual interviews seeking to understand the barriers and facilitators to the adoption of sensor technology in oncology. Through coding and transcripts, a thematic analysis was conducted to create typologies of stakeholder perceptions.

Trustworthiness and Validity

Throughout this entire research study, trustworthiness and validity were maintained by creating parallel questions addressing the same concepts, by using purposeful sampling and utilizing the same sample size and participants and by using convergent data analysis and integration strategy through joint and comparative display of results side by side (Creswell & Plano Clark, 2018). Several methods of verifications where utilized including triangulation,

member checking of interview transcripts, code verification and themes analysis, to ensure both internal and external validity, not to mention controlling for researcher bias (Creswell, 2013).

Ethical Considerations

There were several ethical considerations and challenges that arose before, during and after the conduct of this study. Some of these issues relate to the type, level and depth of consent given by participants in the study. Therefore, this study adhered to the ethical principles outlined in The Belmont Report. The Belmont report provided ethical guidelines to address the issues of respect for the person, beneficence, justice and the selection of human participants in research along with the nature and definition of informed consent (The National Commission for the Protection of Human Subjects of Research, 1979; The Office for Human Research Protection, 1991). This study began by obtaining the appropriate approvals from the IRB to ensure compliance with governmental and university research policies. The participants were provided with a detailed informed consent form outlining their rights and the disposition of any data or information collected on them. This informed consent protocol complied with the common rule and allowed the participants to revoke their consent at any time and for any reason. The informed consent form took the approach of the participant opting out unless they opt in and considered the future possible use of this data. This consent form was provided to them in both electronic and paper forms. The researcher planned to explain, and actively reviewed this form in detail with every individual participant to ensure awareness, understanding and compliance.

Compensation was not provided to offset any loss of work time or travel related expenses. Appropriate access control and security and privacy procedures were followed to

ensure any participant data, information or any contribution to the study is protected and safeguarded.

In a transdisciplinary research study related to a complex health related topic such as cancer, innovation and communication can help bridge the cultural, ethical, use and expectations divides between researchers and participants (Callier, Husain, & Simpson, 2014). Gaining public trust, beginning with the participants, meant engaging in a decision-making process that is transparent, pluralistic, and participatory (Frederic & Lee, 2015). It is also widely understood that participation in research, especially research that has translational qualities, requires diversity and inclusion of various populations (Callier, 2018).

Careful attention to, and respect for, the needs of vulnerable populations was an important part of the role of researchers and health professionals, particularly in the new opportunities we have in translational health science. The study to explore the perception of barriers and facilitators to sensor technology adoption in cancer care holds immense potential to bridging gaps in knowledge. It is a consequential approach to embedding the translational aspect into research and generating new approaches to intervention and care.

Chapter 4 – Analysis

This qualitative study intends to explore the research and practice of wearables and sensor adoption in oncology, and specifically to answer the following two questions:

- **What are the perceived barriers and facilitators described by oncologists and technologists to adopting sensor technology for cancer treatment?**
- **How can adoption be enhanced?**

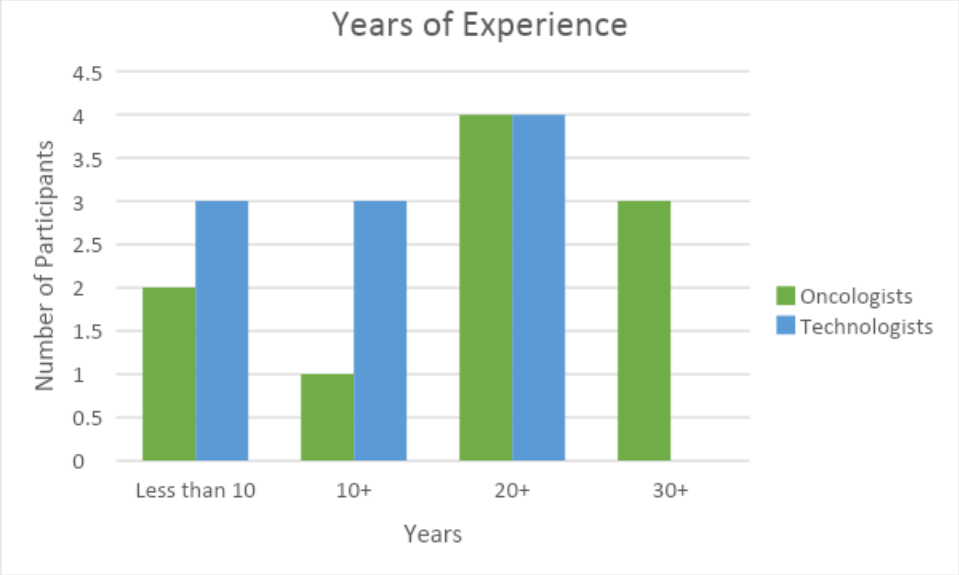
In order to do that, 20 participants were interviewed consisting of 10 oncologists and 10 technologists. Interviews were conducted via phone or via online video conferencing tools. The interviews were recorded and transcribed. The transcribed interviews were provided back to each participant for member checking. 18 participants responded verifying the accuracy of the transcriptions. One individual did not respond, and one individual responded with the point of clarification requesting that a specific reference related to his CEO name be removed, and the researcher obliged and removed the reference.

The interview questions were conceived based on a combined conceptual framework analysis adapted from CFIR (Damschroder, 2009) and Diffusion of Innovation (Rogers, 1995). From the CFIR, three domains were utilized including the inner setting, the outer setting, and the individual involved. Three additional domains from the diffusion of innovation theory were also utilized including individual characteristics, communications, and the decision-making process. Upon verification of the transcribed interviews, the researcher used inductive coding to arrive at key themes from the participant interviews. These themes provide a dynamic view and a window of understanding related the delicate dance between the medical profession, specifically oncology; focused on patient care, and the innovations, led by technologists, that are constantly

disrupting how we do things. These themes are a lens through which we can develop a roadmap to understand these stakeholders and assist in further adoption and translation of key innovations and knowledge into practice.

The participants represented a diverse group oncologists and technologists. The oncologists represented a level of experience ranging from less than five years two over 30 years of practice, with the majority of oncologist participants falling toward the latter, more experienced levels. The technologists represented a range of experience ranging from less than five years to over 20 years of experience, with most technologists falling in the (10+ or higher) category. Figure 7 below depicts the range of experience for both cohorts.

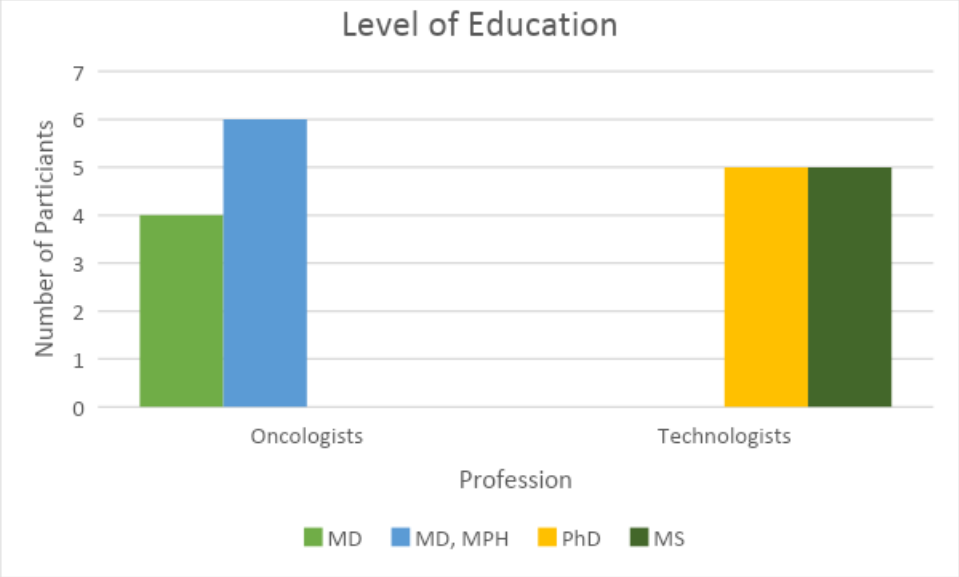
Figure 7: Years of experience for each participant cohort



The level of education was also noted between the two cohorts. Each participant was asked about the highest level of education completed. The breakdown in the oncologist cohort consisted of all ten (10) oncologist having completed a (MD) with six (6) out of the ten (10) having an additional Master of Public Health (MPH) designation. Technologists on the other

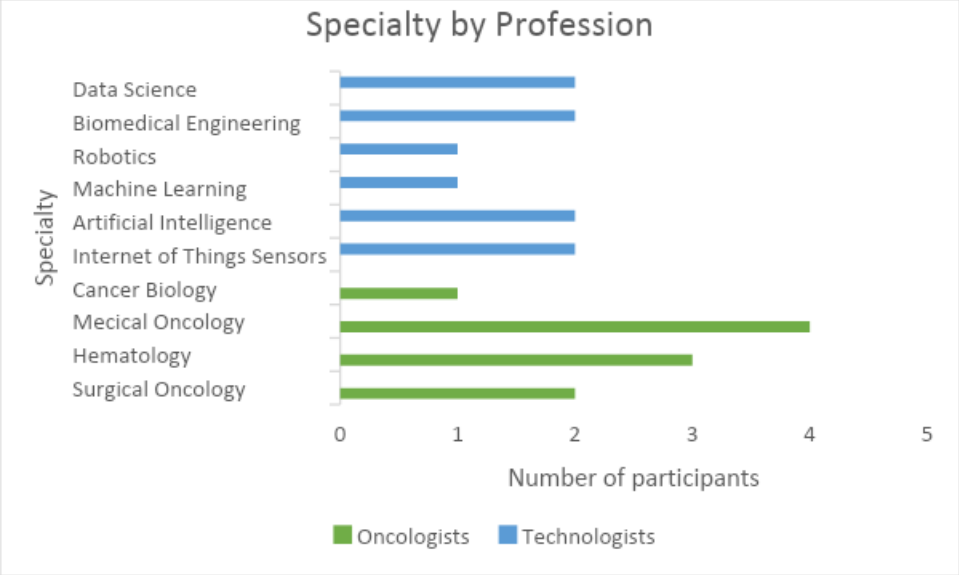
hand were evenly split with half of the cohort having earned a PhD and the other half having earned a master's degree. Figure 8 below depicts the breakdown in the level of education for each cohort.

Figure 8: Level of education for each participant cohort



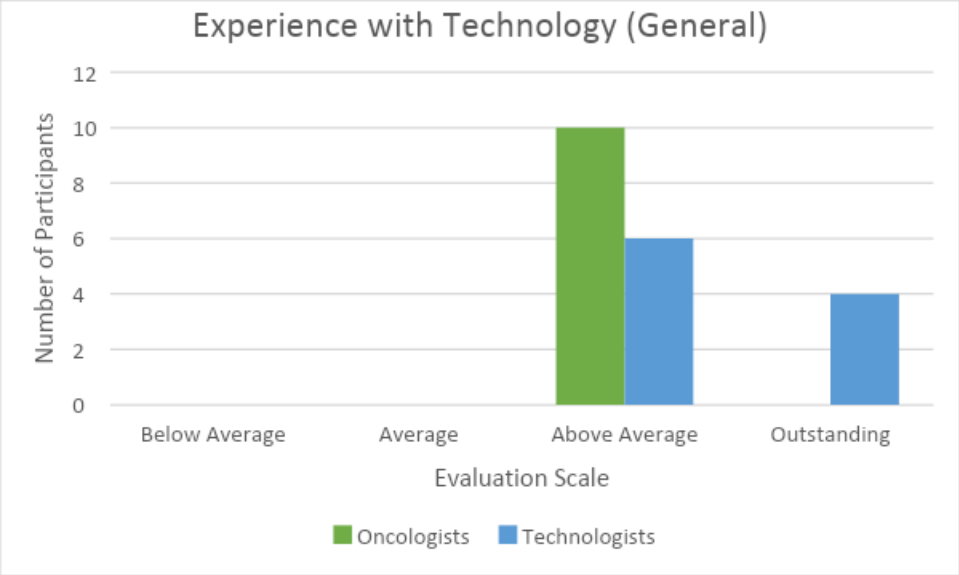
The participants were also questioned about their specialization or specialty area in order to obtain a level of knowledge about their areas of expertise and perspective. Oncologists represented four (4) major areas of practice including Medical Oncology, Hematology, Surgical Oncology and Cancer Biology. All ten (10) oncologists interviewed were practicing physicians with four (4) conducting research or work on trials in a limited capacity. Technologists on the other hand represented several technological areas including data science, biomedical engineering, robotics, artificial intelligence, machine learning and Internet of Things (IoT) sensor designers. All ten (10) technologists were very deep in their areas of expertise and held the highest possible education or professional credentials in the respective fields. Figure 9 below showcases the specialty breakdown by oncologists and technologists.

Figure 9: Specialty by Profession



Every participant, oncologist, or technologist, was asked about their level of aptitudes with technology. This was a general question assessing their own perception of their level of knowledge and what they consider technology is. They were asked to rate themselves as below, average, above average and outstanding. All oncologists rated themselves as above average, while six (6) technologists rated themselves above average and four (4) technologists rated themselves as Outstanding. When each participant was probed further about their technology knowledge, and especially related to sensors and wearables, the technologist retained their assessment, while every single oncologist in the cohort assessed themselves below average when it comes to sensors and wearable technology. Please see Figure 10 below for a graphic depiction of these assessments.

Figure 10: Experience with Technology



Both cohorts of participants indicated that they have extensive experience working with various chronic disease groups such as Diabetes and Alzheimer's disease. However, how they work with these disease group was very different. Oncologists often work with patient who have other chronic conditions and therefore must coordinate care and treatment with a group of other medical professionals for the safety and care of the patient. The oncologist knowledge and interaction with these other disease domains is solely focused on patient care as it relates to the patient's management of the chronic condition while undergoing cancer treatment. On the other hand, technologists interact heavily with these chronic disease domains in terms of developing solutions to help patient with chronic condition manage their treatment, and help clinicians treat and continuously monitor the condition of their patients. This relationship has manifested itself in various medical devices and technologies that aid patient in monitoring their blood sugar levels, movement and vital signs.

When each participant (both cohorts) was asked about their opinion related to why some of these chronic disease domains such as diabetes and Alzheimer's disease were more embracing of sensors and wearable use in patient care and treatment, many answers were suggested

including improved patient outcomes, earlier diagnostics, lower cost, ease of use, supportive payment models and incentives: "It works great in diabetes and Alzheimer's because these sensors can help you possibly diagnose a problem before it becomes huge" (participant 5). "It is easy to use when there is a mechanism to pay for it, insurance, Medicare, etc..." (Participant 19)

When oncologists were asked about their level of engagement with technologists, nine (9) expressed that they have very little to no experience working with technologist in any way. One (1) oncologist had experience since he was working on a research team at an Academic Medical Center. When the same question was asked of technologists and their level of engagement and interaction with oncologists, 80% (8 out of 10) technologists cited that oncologists do not have time and are not interested in collaboration: "They are always busy and have lots of pressure on them. Their hospitals require them to see so many patients. When are they going to find time to learn something new?" (Participant 12)

Several barriers were noted by each participant and they highlight some common themes that are found across both cohorts. One of the biggest barriers in the minds of oncologists was that they thought technologists lack a true understanding of the healthcare system and how patient care works:

> "you get this whipper snapper young guy who thinks he is god's gift to creation, and they sit there telling you how you've done things wrong your entire career. Would you listen to that? I don't. The fact is these tech people have no clue how it is really dealing with patients and being on the front lines. They watch TV and think it is easy and cool. Well, it is not, and we must care about lives. We care about what it does to families. We care about what it does to us and our livelihood if we do not have appropriate outcomes and follow rules. So, before they tell me about a new gadget, they have to walk in my

> shoes and feel and see what I see. Only then, they can design something that actually helps…that works" (Participant 8).

Oncologists also cited the high costs of medical devices and technology and the lack of proper payment mechanisms to address these high costs. Additionally, oncologists spoke of their own lack of time and how busy they are due to their focus on patient care, leaving very little time to experiment or acquire knowledge about new potential innovations. They concluded that there is not a true incentive to make changes. Furthermore, they spoke of the lack of agility in their own organization to communicate and drive innovation. Issues with politics and a non-supportive culture were cited: "I try to stay out of politics because, look, the more I ask for things, means the more I have to put up with politics. So, I just go about my business, smile, and avoid the hassle. My time is valuable, and I'd rather focus on the patient than deal with bureaucracy" (Participant 1). Finally, oncologists highlighted the need to do pilots and to have these pilots evaluated for efficacy and effectiveness purposes. In addition, they named the cumbersome FDA medical device evaluation and approval process and that is not something they are willing to or have the time or interest in dealing with.

Technologists on the other hand, cited their own list of barriers to sensor and wearables adoption in oncology. Chiefly among the barriers was the fact that oncologists are too busy and are not interested in exploring new ways to treat or care for cancer patients. Technologists cited that there is very little incentive for oncologists to innovate and that most healthcare systems and payment models lack the agility and the innovative structure to explore new options. Several technologists spoke of their lack of understanding of the healthcare ecosystem and noted the lack of a "business case" to push these technologies into cancer care. Regarding a business case: "I don't understand why we would go through and build something if the oncologists want to do it

for free, for experimentation. Who is going to pay for the development costs, my time, my invention?" (Participant 20). Furthermore, every single technologist criticized the FDA medical device evaluation process and how it impedes the development and roll out of innovative technologies into healthcare.

Figure 11 below highlights the key barriers to the adoption of sensors and wearable technologies in cancer care as articulated by oncologist and technologist. These barriers listed are a summary of the key discussion points stemming out of the 20 interviews conducted for this research.

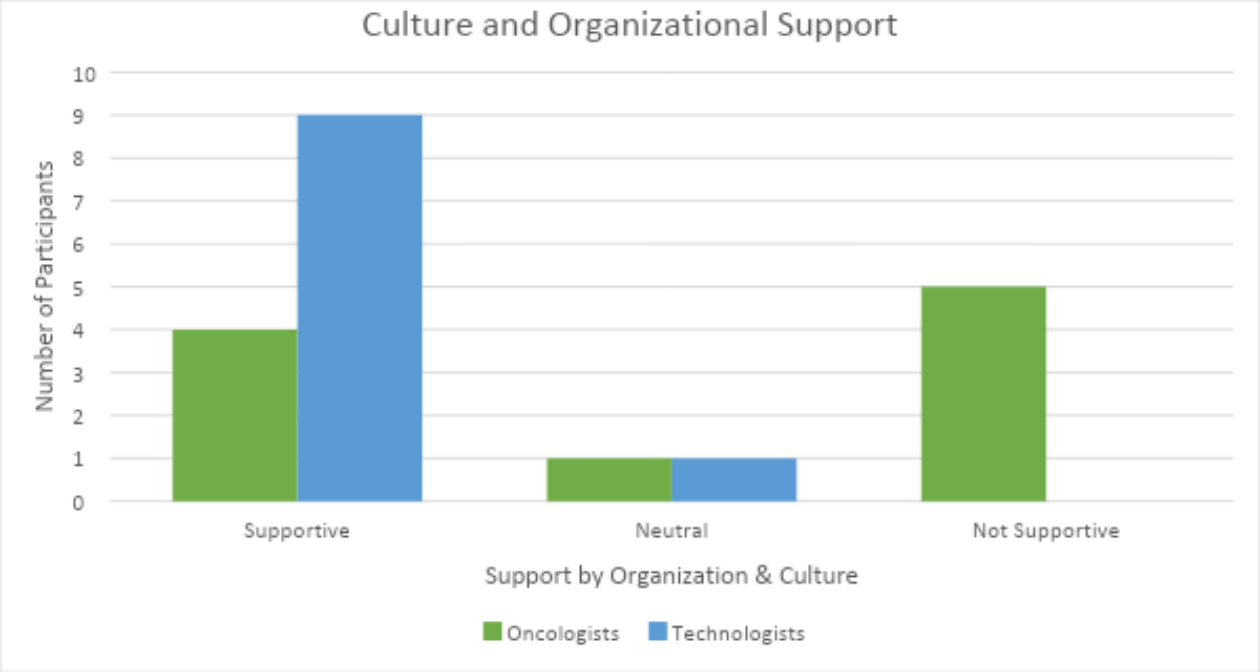
Figure 11: Barriers to the adoption of sensors and wearable technologies in oncology

Cited by Oncologists	Cited by Technologists
Technologists do not understand healthcare	Oncologists are too busy
High costs	Oncologists have very little interest in innovation
Lack of time, patient care is a priority	Lack of incentives
No incentive to change	FDA Process is too cumbersome
Improper payment models	High cost, but costs coming down
FDA process	Lack of Healthcare ecosystem knowledge
Clinical trials, need a pilot	No business case
Technologists only focus on business	Healthcare organizations are too slow
No real innovation process in health organizations	Oncologists think they know everything
Healthcare organizations are not agile	
Difficult to keep up with technology innovation	
Institutional politics and culture	

When oncologists were asked about how they felt about the support provided to them by their organization and about their overall organizational culture, the responses were mixed. Four (4) of the oncologists indicated that their organization was supportive of innovation and encouraged the use of the latest technologies in cancer car. However, five (5) oncologist expressed that their organizations were not supportive and sighted issues related to politics, a lack of innovative culture and a broader distaste for additional costs given their hospital or clinics' low margins. One oncologist was neutral but cited similar issues: "I don't want to appear negative, but I don't think my CEO really cares. We are very ho-hum about it and there is some apathy, so I'll just say we are middle of the road, like…status quo and don't rock the boat" (Participant 10).

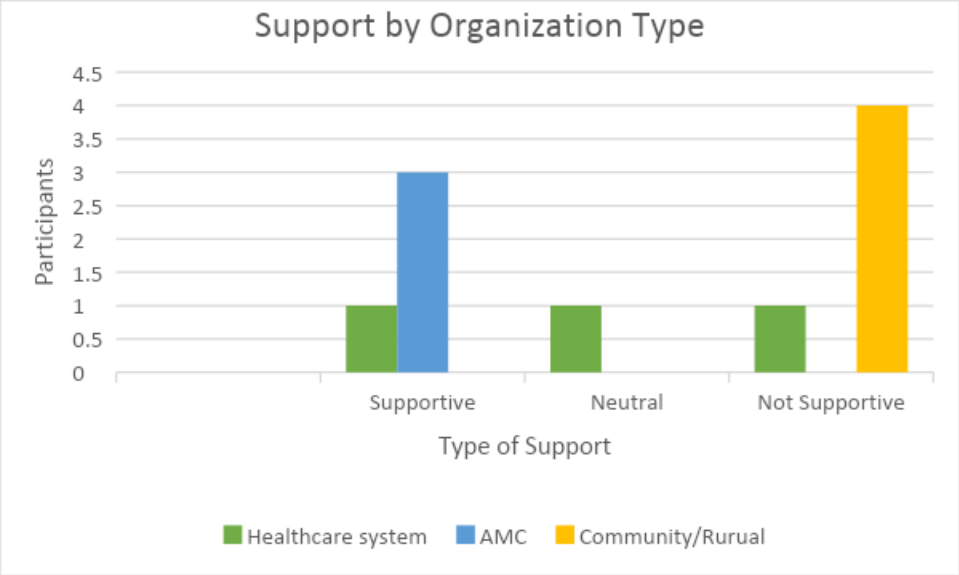
Technologists on the other hand were mostly positive about the support provided to them by their organization. Only one technologist cited the support as neutral. Organizational support: "so critical to have support from your organization. I'm very entrepreneurial and I'm lucky that my company is too. If they weren't then I wouldn't be here talking to you" (Participant 16). Figure 12 below highlights the response by the participants regarding their organizational support and culture.

Figure 12: Culture and Organizational Support



Upon further analysis of the responses from oncologist, it was determined that most of those respondents citing a non-supportive culture were working at community or rural hospitals. Four (4) community or rural oncologists cited a non-supportive culture, while one oncologist from a large healthcare system cited a non-supportive culture. “You lose a lot of data and you gain a lot of data when you talk to community hospital patients and doctors. They just don’t have the same amount of information or capacity” (Participant 4). On the other hand, Academic Medical Centers (AMCs) were noted by participants to be supportive and to have a culture that encourages and fosters innovation. Figure 13 highlights the support level by organization type.

Figure 13: Supportive Culture for oncology innovation by Organization Type



Both oncologists and technologist spoke about and highlighted the importance of communication in order to accomplish their tasks and to continue to gain knowledge. Oncologists indicated that they value their network and leverage it extensively in terms of sharing ideas and treatment plans: “I call on people all the time, talk to them, text them so that I can discuss cases and get second opinions. Like a lifeline when I’m stuck or just want to check myself” (Participant 2). They also value ways to gather knowledge and communicate about new discoveries through conferences and via publications. A few oncologists, those with less than 10 years of practice experience, noted the use of message boards and social media sites like Twitter and Facebook, in addition to the traditional channels of journals, publications and conferences, to remain abreast of the latest developments in cancer care.

Technologists value communication highly but tend to have smaller networks. Their networks are more concentrated and consist of people with similar interests and practice domains. They do participate and attend technology and health related conferences. They do review academic and industry journals, but to a lesser extent compared to oncologists. The value social media apps and messaging boards greatly and connect with people extensively on these

domains. Technologists also participate in small technology centric or innovation centric events such as hackathons and business plan competitions such as Shark Tank. Competitions seemed to resonate: “We get together and really challenge ourselves to come up with something cool, innovative and disruptive” (Participant 15).

Regarding personal attributes that contribute to participant engagement, oncologists touted their desire for knowledge and lifelong learning, patient outcomes, curiosity, and creativity. Two oncologists cited their drive to gain knowledge due to “fear of obsolescence.” “I am terrified of falling behind. When I think about that, I think about my own personal well-being and wealth, livelihood, but I also think about my patients and am I making the right decisions for their care” (Participant 1). Technologist highlighted several personal attributes contributing to their engagement. These attributes include curiosity, drive for innovation, creativity and need to “tinker.” Curiosity was cited by many technologists. “I am so curious about how things work, and I don’t care how long it takes and how much it costs” (Participant 11). “I want to find out why things are the way they are and why do we, for example, in healthcare not ask questions or challenge?” (Participant 18). Drive for innovation was also cited several times by technologists. “I want to build something that will last; that will be remembered” (Participant 19). “What’s the point of doing something if it is not something you will do with a bang?” (Participant 13).

Both oncologists and technologists expressed their desire to collaborate more. When asked what they feel they bring to the table to allow that to happen, oncologist noted that they can bring healthcare expertise and a patient centric view to the discussion, as well as contacts within the healthcare system. Technologists expressed their willingness to engage by supporting conferences and innovation forums and partnering with oncologists to seek funding from various

sources including Federal, State and Local governments, as well as from various other commercial funders and not for profit organizations.

In summary, high level themes emerge based on the overarching structure of the CFIR and the Diffusion of Innovation conceptual frameworks. These key themes are listed below, and they highlight the individual, contextual and characteristics of innovation as levers that must be managed. For a detailed list of key themes and findings from oncologists and technologists, please see Appendix A

Themes

- Both oncologists and technologists are highly educated, deeply experienced, greatly motivated and have a high sense of duty and care. Oncologist to patients, and technologists to innovation.
- Communicate is an essential factor for both sides, coupled with a keen sense of personal aptitude from both oncologists and technologists.
- Neither side understands the mission and corresponding barriers and facilitators of the other
- Barriers to sensor and wearable technology adoption include high cost, lack of time, efficacy of the product/tool, A cumbersome FDA process, fear of change, culture and organizational barriers, lack of funding, and lack of incentives.
- Facilitators or enablers include the desire for collaboration, improved patient outcomes, early diagnostics, continuous monitoring, cost reduction, publications, and conferences.
- Organization and culture are critically important in driving innovation, especially in a community or a rural healthcare setting.

Chapter 5 – Conclusion

There are specific barriers cited by both oncologists and technologists related to the adoption of sensor and wearable technologies in cancer care. Additionally, there are enables or facilitators that can further enhance adoption but require a concerted effort and a methodical process to bring both sides to work on this and bridge the gap. This study brings needed insights to help translate the knowledge of these barriers and facilitators into action. It also highlights suggested options and recommendation to further adoption.

Discussion and Interpretation

The research answered both questions guiding this study: 1) What are the perceived barriers and facilitators described by oncologists and technologists to adopting sensor technology for cancer treatment? And 2) How can adoption be enhanced? The research used both the CFIR and the Diffusion of Innovation Theory to create a combined conceptual framework that not only serves to answer these research questions, but also to provide educational context and action plans, as well as a roadmap for implementation that contributes to implementation science.

Alignment to the Conceptual Framework

This conceptual framework leads us through a process beginning with adaptation, leading to adoption, and furthering into diffusion. It aligns the findings of each component, individual, organizational and cultural to the stages of the framework. For example, organizational components or levers enable and influence how an organization adapts to new innovations, in this instance, the possible use of sensors and wearables in cancer treatment. Individual components or levers such as perception, motivation and self-efficacy influence the deep

adoption of new innovations, thus allowing these new technologies to become permanent and a part of the fabric of oncology care within the organization. Finally, as the use of sensors and wearables becomes enshrined in the typical operations of the medical units, it leads to a renewed sense of innovation leading to a culture that embraces new advances in the field and further sharing, dissemination and collaboration across disease areas and with additional technologies. This cycle is further enhanced by a level of communication between the innovators (technologists) and users (oncologists) who, together through ongoing dialogue and collaboration, can expedite the passage of an innovation through the stages of this framework.

Alignment with Past Research

As gleamed through the literature review for this study, there is extremely limited research available about the use of sensor and wearable technology in oncology. Moreover, as of the time of the study conclusion, there is no published research related to exploring the barriers and facilitators that are impacting the adoption of these technologies in cancer car. This study, with its views and perspective gathering from both oncologists and technologists seeks to shed light on the dynamics present and the potential path forward. Given that it is the first study of its kind to explore these concepts, it might serve as a launching pad to further research in this arena.

Study Insights

The interviews conducted, provided deep insights, and the perspectives shard by both cohorts (oncologists and technologists) allowed for a thorough examination of the situation and the current state. Both oncologists and technologists are highly educated, deeply experienced, greatly motivated and have a high sense of duty and care, oncologist to patients, and

technologists to innovation. The desire to learn and to share learning was evident in every conversation. One could not help but feel the eagerness with which both groups wanted to share their thoughts and opinions. There was a tremendous sense of pride by both sides and a focus on a mission. Oncologists valued their patients above all and were very protective of them. They worked tirelessly to find solutions and treatments to their patients' problems. Technologists were problem solvers. They articulated a vision by which they hope to create and develop new inventions and innovations that can further patiently care and help improve patients' lives.

Barriers

What was very clear in terms of their focus on their priorities, highlighted a glaring issue. The issue is that neither of them were thinking about asking for help or stopping to think about seeking advice or perspective from someone outside of their inner circles. They were in a silo, speaking with only people in their same line of practice and work. Both sides value communication greatly, except they seek it only from likeminded individuals. Based on the research, communication is an essential factor for both sides, coupled with a keen sense of personal aptitude from both oncologists and technologists.

Another key point was that neither side understands the mission and corresponding barriers and facilitators of the other. There was a sense of distrust between both sides about the mission of other. Oncologists thought of technologists as very money driven and were too deep in the "tech" side. While technologists thought of oncologists as too dismissive and with large egos, refusing to listen to or consider new ways of treating patients. These feelings speak to the deep divide and lack of awareness and understanding of what each side does, and why.

So as we outline the barriers, it is important to highlight that despite many perception issues on both sides, the participants as a whole agreed on some aspects of what they determined were barriers to the adoption of sensors and wearables in oncology. High cost was the biggest culprit with both sides agreeing that oncology care is already very expensive for patients and that new sensor technology can be extremely costly, although costs are rapidly declining. Technologist indicated that oncologists do not provide them with adequate time. This may also be a reason why there is very little interaction between the two groups, leading to a lack of communication that is contributing to a lack of understanding. Further barriers cited by both sides included a need for a pilot to establish efficacy and a cumbersome and demotivating FDA process related to new innovations such as drug development and medical devices. Additionally, both sides stated the need for an incentive system and payment protocol that encourages adoption of new technologies.

Enablers / Facilitators

The enablers cited by both groups of participants included the desire for collaboration, improved patient outcomes, early diagnostics, continuous monitoring, cost reduction, publications, and conferences. These enablers highlight the agreement clearly present between the two groups on a path forward and a further need to work together to find a path or a roadmap to adoption. Neither side was shy about sharing their desire to work together for improved outcomes.

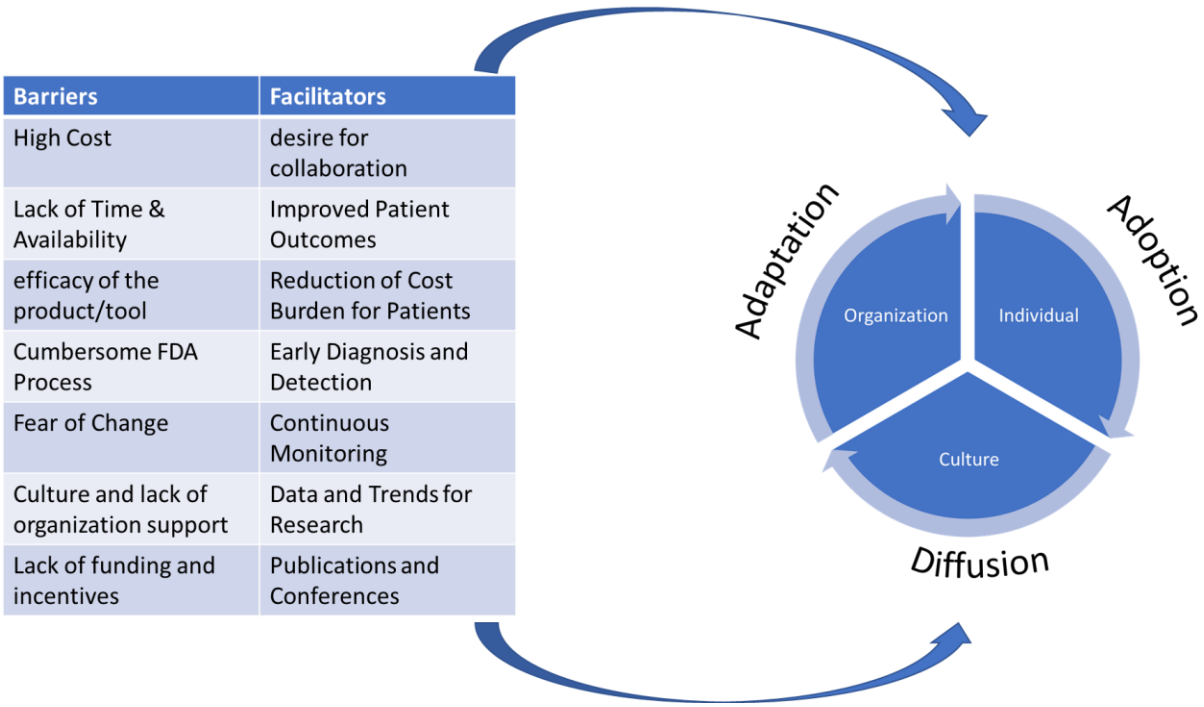
Finally, both sides agreed that organization and culture are critically important in driving innovation, especially in a community or a rural healthcare setting. The community and rural health oncologists stated they feel further disadvantaged as they do not have the resources

Academic Medical Centers have, which leaves their organizations ill equipped to embrace innovation due to the higher costs. Additionally, these same oncologists cited their patient mix being higher risk as their patients tend to be older and with a higher level of comorbidities.

Recommendations

In order to arrive at recommendations to address the barriers and facilitators to sensors and wearables adoption in oncology, we must consider the results of the research, coupled with the conceptual framework developed. With a focus on Adaptation, Adoption and Diffusion, as outlined in Figure 14, we need to think of a phased approach that would facilitate future adoption, while placing the least amount of burden on either oncologists or technologists.

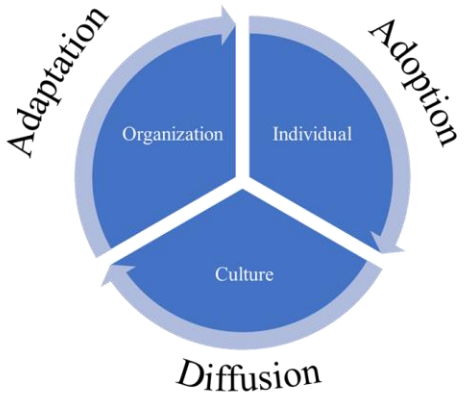
Figure 14: Mapping of findings to the combined conceptual framework



We must align the recommendation to the three elements of the conceptual model and do so in a systematic way taking into consideration the short, medium, and long terms. As we align

the key component of the conceptual model to this timeline, it is critical to map the actions and recommendations accordingly. Figure 15 displays the recommendations against a timeline for implementation.

Figure 15: Recommendations and Suggested Approach



	Short Term	Medium Term	Long Term
	Adapt	**Adopt**	**Diffuse**
Knowledge Sharing Sessions	X	X	X
Conferences	X	X	X
Webinars	X	X	X
Podcasts		X	X
Pilots		X	X
Research			X
Publication			X

According to Figure 15, the recommendations in the short term consist of conducting knowledge sharing sessions between oncologists and technologists to further dialogue about the results of this study and to create and nurture relationships leasing to a better understanding and views by each party. Both sides recommended conferences as a venue, so it seemed to be a natural way to bring both sides together to learn and to share knowledge. The increased awareness coupled with the networking at these conferences can further enhance the collaborations and the collective understanding of the latest technologies and their path to adoption. Webinars are also very helpful and less time consuming to attend and to collaborate on jointly, furthering the ability to hear and expose different perspectives. These steps, in the short term, can help create a foundation of trust and a bridge to knowledge that can serve as a launching pad to next steps on this roadmap.

In the medium term, it is recommended that all the activities in the short term remain, and to add additional engagement activities such as podcasts to create a further sense of collaboration and to allow for differing perspectives. Podcasts were noted by technologists to be extremely effective and cater to their needs. A big component of the medium-term approach is to conduct pilots of some of these new sensor and wearable devices. Working together as a team to create a path to trial some of these solutions could prove very helpful not just in furthering collaboration and propensity to utilize, but to also create trials and testing required for FDA approvals.

Finally, as a longer-term approach, and to diffuse innovation throughout the oncology space, it is recommended that the steps in the short and medium term be continued while adding further enablers to collaboration such as joint research and journal publications. Collaborating on research in terms of pursuits of funders, writing together and working on innovation will be essential in establishing the field of oncology as an innovative field. This approach will further the integration of oncologists and technologists and will create critical advances in research and innovation.

This systematic approach and related recommendations provide a roadmap to guide both oncologists and technologist on a path of joint development and collaboration for the benefit of patients, science, and innovation. This research study is but a first step to furthering the understanding of the barriers and facilitators impacting oncologist and technologists to adopt new solutions in the sensor and wearable technology space. The conceptual framework devised, along with the staged approach in the short, medium, and long term, allows the stakeholders to continuously interact, evaluate and measure impact so that alignment is achieved and a sense of collaboration and buy-in is maintained.

Implications and Furthering the Research Agenda

This study is concerned with identifying the barriers and facilitators to the adoption of sensors and wearable technology in the oncology space, and based on that information, determining possible solutions to enhance this adoption. The implications of this research are far reaching. It is the first research of its kind in this area, as highlighted by the literature review conducted for this study. It provides a high-level roadmap to guide oncologists and technologist on how to communicate and collaborate to advance adoption. Future research stemming out of this study include a deeper technical and scientific analysis of potential areas of treatment focus, a detailed construct along with tools and methods to provide further education and knowledge transfer tools in this space, as well deeper research in the social sciences space to further explore topics such as leadership, motivation, collaboration and knowledge management.

Additional areas worth exploring that would present amble opportunities for further research and exploration include furthering the study of organizational culture and barriers on behavior, institutional politics at healthcare organizations, payment models in light of health reform potential and options, and incentives and how they drive behavior in medicine. A final area of interest is the cumbersome FDA drug development and medical device approval process cited by many participants in this study as a major barrier outside of their control.

Finally, the conceptual framework devised for this study, consisting of a combined approach leveraging the CFIR and the Diffusion of Innovation Theory could be applied to other disease domains, additional technologies, and industries. This framework applies to translational aspects of science in general, as well as education and business. It is a mechanism to manage change management aspects of any innovation and can lead to a methodical approach to implementation at a broader scale.

Implications of COVID19

The results of this study represent the conclusion of this research at a point in time without taking into effect the vast sea change in behavior and business model, brought about by the Covid19 pandemic. This alarming pandemic swept the world quickly, and due to its influence of the way we do business, interact, and treat patient, has impact the way oncologist and technologists may view and consider these barriers and facilitators.

For example, telehealth and virtual visit have become the norm in such a short time. The telemedicine technology, while it has been in place for some time, just became paramount and essential to providing care. Suddenly, ever physician, health administrator, insurance company and patient, is seeking telehealth as a way to conduct and pursue their healthcare needs. Clinicians who shunned technology as being too hard or too complex, have had to embrace within days. Rigid organizations have discovered quickly that if they do not adapt to the changing environment, and quickly, they will perish. Additionally, payment models and incentives to change have now become ripe with innovation and experimentation.

Covid19 has upended the way we do healthcare as a business and as a human function. Now is the time to change the status quo and think outside the box. Innovation flourishes in the most challenging time and human ingenuity is greatest during times of strife. This study highlighted the barriers and facilitators to adopting and integrating sensors into medicine, and specifically, oncology. This vast change by the pandemic to the way we consume and provide healthcare will accelerate innovation and the adoption and integration of new technologies and solutions in health, and will create and enhance communication and collaboration channels that

make it possible to provide new and enhanced patient experiences and provider experiences based on improved outcomes and lower costs.

Reference(s):

Baregheh, A., Rowley, J., & Sambrook, S. (2009). Towards a multidisciplinary definition of innovation. Management Decision, 47(8), 1323-1339. doi: 10.1108/00251740910984578

Bhandari, D., Lopez-Sanchez, I., To, A., Lo, I., Aznar, N., Leyme, A., … Ghosh, P. (2015). Cyclin-dependent kinase 5 activates guanine nucleotide exchange factor GIV/Girdin to orchestrate migration-proliferation dichotomy. Proceedings of the National Academy of Sciences of the United States of America, 112(35), E4874–E4883. https://doi.org/10.1073/pnas.1514157112

Christensen, C. (1997). The innovator's dilemma: when new technologies cause great firms to fail: Harvard Business Press.

Continuing America's leadership: the future of medical innovation for patients : hearing of the Committee on Health, Education, Labor, and Pensions, Senate, 114 Cong. 1 (2017)

Curran, J. A., Grimshaw, J. M., Hayden, J. A., & Campbell, B. (2011). Knowledge translation research: the science of moving research into policy and practice. The Journal Of Continuing Education In The Health Professions, 31(3), 174-180. doi:10.1002/chp.20124

Damschroder, L., Aron, D., Keith, R., Kirsh, S., Alexander, J., & Lowery, J. (2009). Fostering implementation of health services research findings into practice: a consolidated framework for advancing implementation science. Implementation Science, 4.

Dearing, J. W. (2009). Applying Diffusion of Innovation Theory to Intervention Development. Research on Social Work Practice, 19(5), 503–518. http://doi.org/10.1177/1049731509335569

Donzella, V., & Crea, F. (2011). Optical biosensors to analyze novel biomarkers in oncology. Journal Of Biophotonics, 4(6), 442–452. https://doi.org/10.1002/jbio.201000123

Greene, B., Doheny, E., O'Halloran, A., & Anne Kenny, R. (2014). Frailty status can be accurately assessed using inertial sensors and the TUG test. Age and Ageing, 43(3), 406–411. https://doi.org/10.1093/ageing/aft176

Kirk, M., Kelley, C., Yankey, N., Birken, S., Abadie, B., & Damschroder, L. (2016). A systematic review of the use of the Consolidated Framework for Implementation Research. Implementation Science : IS, 11(1), 72. https://doi.org/10.1186/s13012-016-0437-z

Klafke, N., Mahler, C., Hagens, C., Wensing, M., Schneeweiss, A., Muller, A., … Joos, S. (2017). How the Consolidated Framework for Implementation Research Can Strengthen Findings and Improve Translation of Research Into Practice: A Case Study. Oncology Nursing FORUM, 44, E223–e231.

Kochanek, K., Murphy, S., Xu, J., & Tejada-Vera, B. (2016). Deaths: Final Data for 2014. National Vital Statistics Reports : from the Centers for Disease Control and Prevention, National Center for Health Statistics, National Vital Statistics System, 65(4), 1–122.

Marschollek, M., Rehwald, A., Wolf, K., Gietzelt, M., Nemitz, G., zu Schwabedissen, H., & Schulze, M. (2011). Sensors vs. experts - A performance comparison of sensor-based fall

risk assessment vs. conventional assessment in a sample of geriatric patients.(Research article)(Report). BMC Medical Informatics and Decision Making, 11.

Michie, S., van Stralen, M. M., & West, R. (2011). The behaviour change wheel: A new method for characterising and designing behaviour change interventions. Implementation Science, 6:42.

Moloczij, N., Krishnasamy, M., Butow, P., Hack, T., Stafford, L., Jefford, M., & Schofield, P. (2017). Barriers and facilitators to the implementation of audio-recordings and question prompt lists in cancer care consultations: A qualitative study. Patient Education and Counseling, 100(6), 1083–1091. https://doi.org/10.1016/j.pec.2017.01.005

Mueller, E., Cochrane, A., Bennett, W., & Carroll, A. (2018). A survey of mobile technology usage and desires by caregivers of children with cancer. Pediatric Blood & Cancer, 65(11), e27359. https://doi.org/10.1002/pbc.27359

Hung Nguyen, Lebel, K., Bogard, S., Goubault, E., Boissy, P., & Duval, C. (2018). Using Inertial Sensors to Automatically Detect and Segment Activities of Daily Living in People With Parkinson's Disease. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 26(1), 197–204. https://doi.org/10.1109/TNSRE.2017.2745418

Peterson, S., Shinn, E., Basen-Engquist, K., Demark-Wahnefried, W., Prokhorov, A., Baru, C., … Patrick, K. (2013). Identifying Early Dehydration Risk With Home-Based Sensors During Radiation Treatment: A Feasibility Study on Patients With Head and Neck Cancer. Journal of the National Cancer Institute Monographs, 2013(47), 162–168. https://doi.org/10.1093/jncimonographs/lgt016

Popper-Giveon, A., Schiff, E., Hatem, D., Samuels, N., & Ben-Arye, E. (2014). One Hand Cannot Clap -- A Study of Arab Practitioners of Traditional and Complementary Medicine in Israel: Identifying Barriers to Integrative Oncology Care. Explore: The Journal of Science and Healing, 10(6), 364–371. https://doi.org/10.1016/j.explore.2014.08.004

Ricciardi, S., Mey, V., Nannizzi, S., Pasqualetti, G., Crea, F., Del Tacca, M., & Danesi, R. (2010). Synergistic Cytotoxicity and Molecular Interaction on Drug Targets of Sorafenib and Gemcitabine in Human Pancreas Cancer Cells. Chemotherapy, 56(4), 303–312. https://doi.org/10.1159/000320031

Ries, E. (2011). The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses: Crown Business.

Rogers, E. M. (1995). Diffusion of innovations. New York : Free Press, c1995

Rotello, V. (2009). Sniffing out cancer using “chemical nose” sensors. Cell Cycle, 8(22), 3615–3616. https://doi.org/10.4161/cc.8.22.9915

Schwenk, M., Hauer, K., Zieschang, T., Mohler, J., & Najafi, B. (2013). Sensor-derived Physical Activity Parameters Predict Future Falls in Individuals with Dementia. Journal Of The American Geriatrics Society, 61, S95–S96.

Solis, F., & Sinfield, J. (2014). Rethinking innovation: Characterizing dimensions of impact. Paper presented at the ASEE Annual Conference and Exposition: 360 Degrees of Engineering Education, Indianapolis, IN.

Tofthagen, C. (2010). Patient perceptions associated with chemotherapy-induced peripheral neuropathy. Clinical Journal of Oncology Nursing, 14(3), E22–8. https://doi.org/10.1188/10.CJON.E22-E28

Tomuleasa C, Braicu C, Irimie A, Craciun L, & Berindan-Neagoe I. (2014). Nanopharmacology in translational hematology and oncology. International Journal of Nanomedicine, 2014(Issue 1), 3465–3479. Retrieved from https://doaj.org/article/8b29a25463494f839e77c0541e3570c6

Zahiri, M., Chen, K., Zhou, H., Nguyen, H., Workeneh, B., Yellapragada, S., … Najafi, B. (2019). Using wearables to screen motor performance deterioration because of cancer and chemotherapy-induced peripheral neuropathy (CIPN) in adults - Toward an early diagnosis of CIPN. Journal of Geriatric Oncology. https://doi.org/10.1016/j.jgo.2019.01.010

APPENDIX A: KEY STUDY THEMES

Oncologists	Technologists
Majority of participants did not have experience using sensors or wearables in Medical Care	All had PhD or master's in computer science, physics, engineering, or biomedical engineering
All described their technology aptitude in general to be at 7 or 8 on a 10-point scale	Worked in Startups, AMC, Tech companies, FDA
When it came to different types of sensors and wearables, they ranged across the board except very little biosensors	20+ or less than 5 years of experience
Experienced oncologists had extensive experience dealing with patients who had chronic conditions, while younger oncologists did not	Many have never worked with oncologists
Enablers to adoption include improved outcomes, lower cost, ease of use, better payment models, incentives, diagnostic ability, continuous monitoring	All scored themselves high on the technology scale
Oncologists cite their lack of interactions with technologists due to technologists' lack of healthcare understanding, lack of value proposition of tools, high cost, business, and money. Not human oriented, do not understand the problem	Extensive experience with wearables/sensors, all but one knows about biosensors
Most oncologists not engaged with technologists	All worked with various chronic conditions on tools related to movement and continuous monitoring
Barriers to adoption: high cost, lack of time, efficacy of product, FDA process, fear, culture not supportive, no funding, no incentives	Enablers: continuous monitoring, diagnostic need, data acquisition, cost reduction
Conferences, papers, messaging boards are the tools oncologists use to keep up	Not engaged with oncologists. Oncologists not interested citing unproved use case, high costs, lack of time, lack of incentives, current state working
Awareness was mixed	Technologists try to communicate via conferences and technical papers
Personal Attributes: curiosity, desire to learn, creativity, fear of obsolescence, tinkering	Technologists generally were satisfied with the support and culture of their organizations
Maturity and experience mattered greatly	Networking and collaboration are very healthy

AMC vs community, large/city vs small/rural	Personal Attributes: curiosity, desire to learn, creativity, fear of obsolescence, tinkering
Network was mixed	Maturity and experience mattered, but also you and new technologists are proven valuable
Communication is important but there is no time except conferences and papers	communication is very important when developing tools and products, but only comfortable with other technologists. Difficult to communicate to medical community and especially oncologists
50/50 supportive/not supportive organization/culture	They felt that they have the knowledge, know-how and tools to create disruptive technologies for oncology
Ability to influence. Yes	They want oncologists to be partners and to collaborate
policies and procedures not supportive to innovation	They want to collaborate, understand, and pilot innovations with oncologists
Ideas: engage with technologists, collaborate	Barriers: time, cost, lack of incentives, FDA process, business case, funding
Partner with or have leading role in development and adoption	opportunities: Cost savings, improved outcomes, quality of life, diagnostics
Suggestions: webinars, webcasts, conferences, panels,	Engagement through conferences, innovation talks, webinars, and podcasts

APPENDIX B: RECRUITING EMAIL MESSAGE

Dear Participant

You are being asked to take part in a research study about the perceived barriers and facilitators experienced by oncologists and technologists to the adoption of wearable and sensor technology in Cancer care. The intent of this study is to explore, understand and describe the barriers and facilitators to the adoption of wearable and sensor technology in oncology. By doing this study, we hope to learn about individual and contextual factors affection decisions related to the adoption of sensor and wearable technologies in cancer care.

As a participant in this study, you will have the opportunity to provide insights and perspective related to critical factors impacting the adoption of sensor and wearable technology in healthcare. This study will strive to understand the potential barriers to sensor technology adoption and the impact on usability by oncologists to treat cancer patients. These sensors may hold great promise in lessening the burden of cancer treatment and pain on patients and their loved ones and may even play an integral role in saving lives. To that end, the research questions aim to understand:

- **What are the perceived barriers and facilitators described by oncologists and technologists to adopting sensor technology for cancer treatment?**
- **How can adoption be enhanced?**

We expect that you will be interviewed for the purpose of this research for a duration of 60-90 minutes in order to collect the information required.

Kindly, let me know if you are able and willing to participate in this study and provide dates and times that would work for your schedule.

Sincerely,

Sam Hanna

PhD Student

APPENDIX C: INFORMED CONSENT FORM

Informed Consent for Participation in a Research Study

Title of Research Study: **Sensors and Wearables in Oncology: A study of the Barriers and Facilitators to Adoption**

Investigator: ***Dr. Leonard Friedman, Professor in Health Management and Policy, The George Washington University***

Wisam "Sam" Hanna, PhD Student Candidate

Key Information:

You are being asked to take part in a research study about the perceived barriers and facilitators experienced by oncologists and technologists to the adoption of wearable and sensor technology in Cancer care. This page will give you key information to help you decide whether you want to participate in this study. More detailed information can be found on the next pages. Ask the research team questions during the consent process, and use the contact information on this form to ask questions later.

WHAT IS THE PURPOSE, PROCEDURES, AND DURATION OF THIS STUDY?

The intent of this study is to explore, understand and describe the barriers and facilitators to the adoption of wearable and sensor technology in oncology. By doing this study, we hope to learn about individual and contextual factors affection decisions related to the adoption of sensor and wearable technologies in cancer care. Your participation in this research will last about 60-90 minutes to complete the interview.

WHAT ARE THE REASONS YOU MIGHT CHOOSE TO VOLUNTEER FOR THIS STUDY?

As a participant in this study, you will have the opportunity to provide insights and perspective related to critical factors impacting the adoption of sensor and wearable technology in healthcare. For a complete Description of benefits please refer to the Detailed Consent.

WHAT ARE THE REASONS YOU MIGHT NOT CHOOSE TO VOLUNTEER FOR THIS STUDY?

You may choose not to participate in this study if you are unavailable and with limited time. Additionally, you may refrain from participation if you perceive a conflict of any kind between you and the topic of this study. For a complete Description of risks please refer to the Detailed Consent.

DO YOU HAVE TO TAKE PART IN THIS STUDY?

You do not have to take part in this research. It is your choice whether you want to take part. You can agree to take part and later change your mind. If you choose not to take part or choose to stop taking part at any time, there will be no penalty to you or loss of benefits to which you are otherwise entitled.

As a student/employee, if you decide not to take part in this study, your choice will have no effect on your academic status or class grade(s) or employment status.

WHAT IF YOU HAVE QUESTIONS OR CONCERNS?

The person in charge of this study is Dr. Leonard Friedman (Principal Investigator, PI. If you have questions, suggestions, or concerns regarding this study or you want to withdraw from the study his contact information is:

Leonard H. Friedman, PhD, MPH, FACHE
Professor and Director
Master of Health Services Administration Program
The George Washington University

Department of Health Services Management and Leadership
2175 K Street NW, Suite 320

Washington, DC 20037

(202) 994-5561 (phone)
(202) 994-5577 (fax)
friedmal@email.gwu.edu

This research is being overseen by an Institutional Review Board ("IRB"). You may talk to them at 202-994-2715 or via email at ohrirb@gwu.edu if:

- You have questions, concerns, or complaints that are not being answered by the research team or if you wish to talk to someone independent of the research team.
- You have questions about your rights as a research subject.

Detailed Consent Form:

Why am I being invited to take part in a research study?

We invite you to take part in a research study because you are either an oncologist performing care or research in the oncology space, or a technologist who is actively involved in the design, development and launch of technologies related to wearables and sensors in the medical space.

Who can I talk to if I have questions?

If you have questions, concerns, or complaints, or think the research has hurt you, talk to the research team at

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This research is being overseen by an Institutional Review Board ("IRB"). You may talk to them at 202-994-2715 or via email at ohrirb@gwu.edu if:

- You have questions, concerns, or complaints that are not being answered by the research team or if you wish to talk to someone independent of the research team.
- You have questions about your rights as a research subject.

Why is this research being done?

The use of sensor technology has become an integral component of our lives and daily routine. We find sensors in our smart phones, wearable devices such as watches and blue tooth headsets, thermostats, and speakers. These sensors record and collect data about what we do and in return, provide tailored experiences and conveniences without much of a thought on our part. Sensor have found their way into medical practices, however, there remains a level of skepticism, distrust, and discomfort with the use of sensor technology in the oncology space. While there are many advances in sensor and wearable technology, the adoption rate by oncologists has been slow. This slow or lack of adoption has a deep impact on the care, comfort, and potential survival of cancer patients. This study intends to describe barriers and facilitators to sensor technology adoption in oncology, then map those barriers and facilitators across two sets of stakeholders (oncologists and technologists).

A good example of the continued focus on infusing technology and innovation (specifically wearables) can be found in the latest efforts by the National Cancer Institute (NCI) to encourage a conversation around cancer and the potential of wearable technology infusion. NCI has begun to create periodic conferences; bringing together scientists, medical informaticists, oncologists, molecular biologists, sensor and device technologists and manufacturers to discuss, plan and address the possibilities related to the intersection of wearable technologies and cancer care. To that end, understanding the perceived barriers by patients, oncologists, and technology entrepreneurs to the adoption of wearable technologies for cancer treatment is essential to affecting the use of these innovative treatments by cancer patients. (Ries, 2011; Thaler & Sunstein, 2008)

Purpose and Research Questions.

This study will strive to understand the potential barriers to sensor technology adoption and the impact on usability by oncologists to treat cancer patients. These sensors may hold great promise in lessening the burden of cancer treatment and pain on patients and their loved ones and may even play an integral role in saving lives. To that end, the research questions aim to understand:

- **What are the perceived barriers and facilitators described by oncologists and technologists to adopting sensor technology for cancer treatment?**
- **How can adoption be enhanced?**

Statement of Potential Impact.

The use of sensors in oncology and the continued adoption of new and effective sensor technology in cancer treatment will provide a platform for future discoveries and advances for the benefit of patients. Using sensor technology, oncologists can provide tailored therapies coupled with continuous measurement for an optimal, effective, and efficient treatment.

How long will I be in the study?

We expect that you will be interviewed for the purpose of this research for a duration of 60-90 minutes in order to collect the information required.

How many people will take part in this research study?

We expect about 20 people will take part in the entire study.

What happens if I agree to be in this research?

We expect that we will schedule a 60-90 minute interview asking you some basic information about your practice, what you do, and your experience with sensors and wearables in oncology. Interviews will be recorded then transcribed. All personal identifying data will be masked and deidentified for the purpose of this research and the final analysis and data presentation. The subject will interact with the Primary Investigator and the Student solely. It is anticipated the research will be complete in the summer of 2020 with dissertation defense in fall of 2020.

Summary of the Methodology.

The research study will follow a qualitative approach. This study aims to:

3. Describe how oncologists and technologists regard wearable/sensor innovations related to cancer treatment. Through individual interviews conducted with 10 oncologists and 10 technologists, or until data saturation is reached, I plan to understand:
    - How do oncologists view, understand and approach new innovations related to cancer treatment?
    - For both oncologists and technologists, what are the barriers and facilitators that impact adoption
    - What do technologists need in terms of key knowledge and how do they obtain it in order to develop and facilitate the introduction of new innovative cancer treatment technologies?
    - How does this knowledge of the barriers and facilitators advance the use of sensor and wearable technology in cancer care?

4. Conduct a thematic analysis of attitudes, barriers, and facilitators described by oncologists and technologists in reference to implementation (adoption and sustainability) of technology. The thematic analysis will draw on data from interviews.

What happens if I agree to be in research, but later change my mind?

You may refuse to participate, or you may discontinue your participation at any time without penalty or loss of benefits to which you would otherwise be entitled.

If you decide to leave the research, please contact the research team so that they can remove you from the research and any data collected will be destroyed.

Is there any way being in this study could be bad for me?

While we strive to protect all participants from any foreseeable risks, there are may be instances where the participant encounters difficulties beyond our control. These risks maybe psychological or emotional after thinking about or conversing about the topics related to this research.

Generally, this is a qualitative study with interviews so the risk should be minimal, and the research team will strive to make the process as simple and straightforward as possible. The risks and discomforts associated with participation in this study are not expected to be greater than those ordinarily encountered in daily life or during the performance or routine physical or psychological examinations or tests.

What happens if I believe I am injured because I took part in this study?

You should promptly notify the research team in the event of any injury as a result of being in the study. If you believe that you have been injured from taking part in this study, you should seek medical treatment from GWU Hospital and/or the GWU MFA or through your physician or

treatment center of choice. Care for such injuries will be billed in the ordinary manner to you or your insurance company. You will not receive any financial payments from GWU, GWU Hospital and/or the GWU MFA for any injuries or illnesses. You do not waive any liability rights for personal injury by signing this form.

Will being in this study help me in any way?

[Include if there are no benefits to participation. Otherwise delete]. Participation in this study could be beneficial for the participant in that they may be a part of a research study that has the potential to advance science and research in an emerging field.

What happens to my information collected for the research?

To the extent allowed by law, we limit your personal information to people who must review it. We cannot promise complete secrecy. The IRB and other representatives of this organization may inspect and copy your information.

The privilege of confidentiality does not extend to information about sexual or physical abuse of a child. If any member of the research team has or is given such information, he or she is required to report it to the appropriate authority or agency, such as child protective services, a law enforcement agency, or your State's toll-free child abuse reporting hotline. The obligation to report includes past and current alleged or reasonably suspected abuse as well as past or current known abuse. Examples of such abuse include physically harming your child or having inappropriate sexual contact with your child.

Are there any costs for participating in this research?

There are no costs for this research except for the time required of the participant to be interviewed by the research team.

Signature Block for Adult

By signing below, you agree that the above information has been explained to you and you have had the opportunity to ask questions. You understand that you may ask questions about any aspect of this research during the course of the study and in the future. Your signature documents your permission to take part in this research.

_____

Printed name of subject

_____ _____

Signature of subject Date

APPENDIX D: AUDIO/VIDEO PERMISSION FORM

Audio/Video Permission Form

I hereby authorize _____ to use my video image and/or audio recording in her/his video for the project entitled, ***Sensors and Wearables in Oncology: A Qualitative study of the barriers and facilitators to adoption*** , in her/his presentation. I have indicated below the name I wish to appear with my image and/or voice. I understand that by signing this form, I am allowing her/him to use my image and/or voice for this expressed purpose. I further certify that I am over the age of 18 years.

Name (Print): _____

Signature: _____

Date: _____

Please initial: Video only: _____
Audio only: _____
Audio and video: _____

Name to be used with video/audio in presentation

(Please print clearly) _____

Investigator's initials _____

APPENDIX E: INTERVIEW QUESTIONS – ONCOLOGISTS

Sensors in Oncology – Interview questions

- Interviewer to provide overview of research aim
- Interviewer to provide overview of consent form and go through it thoroughly with each participant
- Interviewer to provide key definition of terms such as wearables and sensors and to discuss related use in the field.

Questions for Oncologists:

- Please provide an overview of your background and experience including
    - Education
    - Work history
    - Years of experience
    - Area of specialization or interest
- Describe your experience with using technology in cancer care
- How would you describe your level of technology aptitude (1=low, 10=high)? Why?
- What is your general experience with wearable technologies?
- Please provide your detailed experience based on the following three tiers of technology:
    - Movement, ambient, sensing

    - Monitoring, vital signs
    - Biosensors

- Describe your experience working with Chronic Disease Domain Experts in areas such as Alzheimer's disease and Diabetes.
- What are some of the enablers to implementing senor technology in these disease domains?
- Describe your experience working with technologists; those who are looking at or building innovative new devices and mechanisms to treat cancer.
- How engaged are you with technologists? Why or why not?
- What were some of the detractors or barriers to using technology innovation?
- How did you overcome these barriers and what techniques did you utilize to do so?
- What contextual factors impacted your progress?
- Describe your level of awareness about the latest technologies in this space? How did you become aware or increase your knowledge?
- What personal attributes do you think contributed to your level of engagement? Please provide up to three attributes
- Do you think your level of experience and maturity in the field contributed to your level of engagement? Why or why not? How did it contribute?
- Describe how your organization structure aided or detracted from your level of engagement with technologists or wearable and sensor technology in cancer care?

- How did you network enhance or limit your engagement?
- Describe the role of communication in how you learned, engaged, and use wearable and sensor technology in oncology
- What was your experience in terms of communication and how did it impact your engagement?
- Describe the culture of your organization? Is it supportive, entrepreneurial, rigid, etc...?
- Do you feel that you are the requisite and needed resources to implement changes and infuse new technologies in oncology protocols? (Resources can be funding, staffing, support, etc...)
- How do current policies and procedures in your organization affect such technology infusion? Are they supportive or preventive?
- What role should practicing oncologists play in such policy and practice decision? Why?
- What would you have done differently?
- What do you see as barriers to adoption in oncology?
- What opportunities do you see in this space?
- What do you recommend as next steps to increase adoption and uptake?
- What resources can you bring to this ongoing dialogue?
- What suggestions do you have for next steps regarding communication with stakeholders??

APPENDIX F: INTERVIEW QUESTIONS – TECHNOLOGISTS

Questions for Technologists:

- Please provide an overview of your background and experience including
    - Education
    - Work history
    - Years of experience
    - Area of specialization or interest
- Describe your experience working with oncologists
- How would you describe your level of technology aptitude (1=low, 10=high)? Why?
- What is your general experience with wearable technologies?
- Please provide your detailed experience based on the following three tiers of technology:
    - Movement, ambient, sensing
    - Monitoring, vital signs
    - Biosensors
- Describe your experience working with Chronic Disease Domain Experts in areas such as Alzheimer's disease and Diabetes.
- What are some of the enablers to implementing senor technology in these disease domains?
- How engaged are you with oncologists? Why or why not?

- What were some of the detractors or barriers to using technology innovation in oncology?
- How did you overcome these barriers and what techniques did you utilize to do so?
- What contextual factors impacted your progress?
- Describe your level of awareness about the latest medical innovations in this space? How did you become aware or increase your knowledge?
- What personal attributes do you think contributed to your level of engagement? Please provide up to three attributes
- Do you think your level of experience and maturity in the field contributed to your level of engagement? Why or why not? How did it contribute?
- Describe how your organization structure aided or detracted from your level of engagement with technologists or wearable and sensor technology in cancer care?
- How did you network enhance or limit your engagement?
- Describe the role of communication in how you learned, engaged, and use wearable and sensor technology in oncology
- What was your experience in terms of communication and how did it impact your engagement?
- Describe the culture of your organization? Is it supportive, entrepreneurial, rigid, etc...?
- Do you feel that you are the requisite and needed resources to implement changes and infuse new technologies in oncology protocols? (Resources can be funding, staffing, support, etc...)

- How do current policies and procedures in your organization affect such technology infusion? Are they supportive or preventive?
- What role should practicing oncologists play in such policy and practice decision? Why?
- What would you have done differently?
- What do you see as barriers to adoption in oncology?
- What opportunities do you see in this space?
- What do you recommend as next steps to increase adoption and uptake?
- What resources can you bring to this ongoing dialogue?
- What suggestions do you have for next steps regarding communication with stakeholders??
- What advice do you have for the clinician regarding adoption of future innovation?