2017

Assessing patient and caregiver intent to use mobile device videoconferencing for remote mechanically-ventilated patient management

Brian R. Smith

Assessing Patient and Caregiver Intent to Use Mobile Device Videoconferencing for Remote Mechanically-Ventilated Patient Management

by

Brian R. Smith

Dissertation

Submitted to the College of Technology

Eastern Michigan University

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY
Technology
Concentration in Information Assurance and Cyber Defense

Dissertation Committee:

John C. Dugger III, PhD, Co-Chair

Dorothy K. McAllen, PhD, Co-Chair

Bilquis J. Ferdousi, PhD

Stephanie E. Newell, PhD

Jeanette P. Brown, MD, PhD

April 25, 2017

Ypsilanti, Michigan

Dedication

This dissertation is dedicated to the patients, family or friend caregivers, and professional caregivers—both at home with patients and in the adult Assisted Ventilation Clinic. Some questionnaire data collection can be rather impersonal, such as sending emails and receiving the responses. I was privileged to experience life in the Assisted Ventilation Clinic and appreciate the complexity of care provided. The courage and attitude of those dealing with neuromuscular disorders and spinal cord injuries were inspiring.

My first day in the clinic I accompanied Armando, a respiratory therapist, into a patient room, to meet a patient. Armando asked him how he was doing. Although he could not move from the neck down, he replied, “I'm having a great day!” How can I ever allow myself to have a bad day again after hearing such a positive response? However, what I found was an attitude among those using mechanical ventilators that this is just normal everyday life, no big deal. One person, who had been on a ventilator for 24 years, shared a story about her ventilator breaking down at the mall. Although she didn't have any diaphragmatic muscle strength, she had strength in her hands and arms … and was working her own bag valve mask so she could keep breathing until a replacement ventilator arrived.

Caregiver burnout is a common topic in the research literature. I am also amazed at the strength of caregivers to be there to help. Family or friends take on the responsibilities of caring for someone who is often 100% dependent upon them to keep them alive. Also, those clinicians in the Assisted Ventilation Clinic care daily for those often on an accelerated path to the next life. It is obvious that they make a big difference in the lives of those dealing with neuromuscular diseases and spinal cord injuries coming to the AVC.

Acknowledgments

Speaking of dedication, I never could have completed this dissertation without the guidance, encouragement, and feedback of Dr. John C. Dugger, III, and my committee members. Dr. Dugger went beyond his responsibilities (even after retiring from EMU) to help me achieve my goal of completing this dissertation. I also want to thank my dissertation committee members who made time in their busy schedules to support my research. They are Dr. Dorothy McAllen, Dr. Stephanie Newell, Dr. Bilquis Ferdousi, and Dr. Jeanette Brown. I also want to acknowledge Dr. McAllen for becoming a co-chair, along with Dr. Dugger, and especially for the extra motivation in the final days to get this dissertation into the end zone.

Dr. Jeanette Brown, MD, PhD, integrated me into the Assisted Ventilation Clinic Tuesday/Wednesday clinical rotations, saw value in this research, and provided valuable input. Three other key people in the Assisted Ventilation Clinic who partnered and supported me in many ways included Julie Hanley (NP), Armando Kurili (RT), and Kimberly Rochefort (RN)—thank you all for your help.

I also want to acknowledge my four wonderful children, their spouses, and my six grandchildren (with one on the way). Each one of you is very gifted and making positive contributions to this world and those in need. I am very proud of each one of you and your academic and professional accomplishments—but more importantly, your character. You are all exceptional and I am blessed!

I also want to acknowledge Dr. Rashid Bashshur, a mentor, guru, and godfather of telemedicine. What an honor to co-author a couple of papers with you and discuss telemedicine almost daily for several years.

Finally, to the God of "IT BE OK"—it has been and will be. Thank you.

Abstract

The Michigan Medicine adult Assisted Ventilation Clinic (AVC) supports patients with neuromuscular disorders and spinal cord injuries and their caregivers at home, helping them avoid expensive emergency department visits, hospitalization, and unnecessary or excessive treatments. Mobile device videoconferencing provides an effective capability for remote mechanically-ventilated patient management but must rely upon an unknown infrastructure comprising patient and caregiver mobile device ownership, connectivity, and experience—and *intent to use* the service if provided. The purpose of this study was to measure the extent of this infrastructure and the *perceived ease of use*, *perceived usefulness*, and *intent to use* this mobile device capability using a questionnaire based on the technology acceptance model (TAM).

Of 188 patients and caregivers asked, 153 (n = 153) respondents completed a questionnaire comprised of 14 demographic and 24 Likert-type questions. Inferential results indicated a significant correlation between *perceived ease of use* (PEU) and *perceived usefulness* (PU) of mobile devices in remote care and their *intent to use* them (sig. < .001). Also, mobile device *own/access* significantly correlated with PEU and PU (p = .003 & .004, respectively), but not *intent to use*. No single demographic variable (age, distance to AVC, diagnoses, mobile device experience, tracheostomy, etc.) significantly correlated with *intent to use*. Descriptive results indicated a significant patient/caregiver provided infrastructure: 96% have cellular/WiFi/Internet access, 91% own or have access to mobile devices, 77% have downloaded apps, 68% have used videoconferencing, and 80% own between two and five ICT devices.

Exploratory factor analysis (EFA) and Likert variable analysis were used to assess the construct validity of the TAM based upon the AVC data collected. Both the EFA and the Likert variable analysis resulted in five factors suggesting an alternative model of the data may better represent the AVC population than the TAM. The EFA five factors explained 75% of the variance in the data; the Likert five factors included *concept*, *how operationally*, *hands-on/ability*, *health beliefs*, and *social influence*. Overall, 80% of the respondents agreed with *intent to use* mobile devices in remote care using this patient- and caregiver-owned infrastructure. Six suggestions for related future research are also provided.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

Many patients with neuromuscular diseases or spinal cord injuries must rely upon long-term mechanical ventilation to survive. Researchers examined the top 24 of approximately 30 different types of neuromuscular diseases and found the prevalence is estimated to be approximately 160 neuromuscular disease patients per 100,000 people (Deenen, Horlings, Verschuuren, Verbeek, & van Engelen, 2015). With a current world population of over 7.4 billion and the U.S. population of approximately 323 million, the prevalence of neuromuscular diseases is almost 12 million globally and over 500,000 in the U.S., respectively (Meter, 2015). Additional numbers added to those with neuromuscular disease patients include those with spinal cord injuries who were alive in 2014, which were estimated between 240,000 and 337,000 (SCI Facts, 2015). Thus, the total number of patients with neuromuscular diseases and spinal cord injuries in the U.S. alone is approaching a million patients. Globally, it is estimated that between 250,000 and 500,000 new spinal cord injuries occur each year (WHO, 2016).

The complexity of care is significant for those with spinal cord injuries and neuromuscular disease patients who require mechanical ventilation. The need for mechanical ventilation increases as neuromuscular diseases progress to the later stages and the higher the level of the spinal cord injury—the most severe spinal cord injuries are located above the fourth cerebral vertebrate (C4). Mechanical ventilation is usually initiated in a hospital setting such as the intensive care unit (ICU) or emergency department. Due to high in-hospital costs and attempts to locate the patient in a more comfortable environment, mechanically-ventilated patients are being transferred to the home environment, where they can be cared for by a nurse or family member (King, 2012). However, regardless of location, the need for complex care remains with much of the burden of care being shifted from the ICU or hospital staff to the remote nurse, caregiver, or family member (Pagnini et al., 2012).

Until recently, the complexity of caring for home mechanically-ventilated patients often resulted in caregivers taking the ventilated patient to an emergency department where they were either unnecessarily admitted to the hospital or given unnecessary treatments. To help provide an intervening service to care for home mechanically-ventilated patients, the Michigan Medicine Department of Internal Medicine established the adult Assisted Ventilation Clinic. Staffed with physicians, respiratory therapists, nurse practitioners, and other clinicians specifically trained to manage mechanically-ventilated patients, they provide several service options: (a) patients can come from home to the Assisted Ventilation Clinic, (b) respiratory therapists can travel to the patient's home, or (c) patients/caregivers can call the clinic by telephone and discuss the issues they were unsure how to manage. These Assisted Ventilation Clinic services and protocols have avoided many unnecessary hospitalizations, emergency department visits, and treatments (Kuo & Carroll, 2016; Morin, Alvey, Murphy, & Glader, 2016; Smith, Kurili, & Hanley, 2014). This Assisted Ventilation Clinic support team has also helped remote caregivers by allowing them to share the burden of care with the Assisted Ventilation Clinic staff.

Although the telephone-only support system has been helpful in sharing the burden of home ventilated patient care, it has several limitations rooted in uncertainty and delay. Uncertainty is inherent in telephone communication in two ways: (a) the caregiver's description doesn't always match the clinician's perception of what is being described, and (b) it is difficult to verify that the caregiver is correctly executing steps or actions the clinician is guiding them through verbally. Uncertainty is even more pronounced when trying to describe the color of a wound or the viscosity of sputum. Delay is introduced simply by verbally having to describe which ventilator screen is being displayed, the appearance of waveforms, and even which ventilator is being used (Smith et al., 2014). In many cases, the situation is time critical where delay or incorrect ventilator settings can result in patient injury and even possibly death.

A 2014 U.N. study revealed that of the world's estimated 7 billion people, 6 billion have access to mobile phones while only 4.5 billion have access to working toilets (PhonesThrones, 2014). The ubiquitous proliferation of mobile devices, such as Apple iPhones and Android smartphones, with high resolution cameras, processors, WiFi/cellular/Internet communication access, touchscreens liquid crystal displays (LCDs), and sensitive microphones, open up the possibility of using them in caring for home mechanically-ventilated patients. Preliminary testing has demonstrated that mobile device videoconferencing is an effective tool for remote mechanically-ventilated patient management (Smith et al., 2014).

Utilizing patient owned mobile devices (or accessible through a caregiver or family member) is essential since providing mobile devices for patients is cost prohibitive. It is estimated that the cost for purchasing a smartphone and service for two years is approximately $3,200 (PC World, 2015). The Assisted Ventilation Clinic currently supports approximately 670 patients using mechanical ventilation or respiratory-assistance, which would result in a cost of $1.8M to provide smartphones and services for all these patients and caregivers. To provide equal care to all patients in the Michigan Medicine ACO (the accountable care organization—currently has 120,000 members) would cost $384M for two years. Thus, providing mobile devices to all patients is cost prohibitive, but utilizing patient-owned mobile devices is potentially feasible.

Research is needed to determine the effectiveness of using mobile devices in caring for mechanically-ventilated patients at home. The Assisted Ventilation Clinic and Virtual Health groups have performed preliminary investigations using action research methodology under an umbrella of clinical quality improvement to identify technical and clinical dependent and independent variables. Remote ventilated patient management feasibility testing has also been performed with three people who used mechanical ventilation and have tracheostomies using a grounded theory methodology. The feasibility of remotely guiding a caregiver using an iPad in the clinic and a mobile device remotely has also been tested in a Zero Ventilator Knowledge test. Additional qualitative research is needed to identify all relevant variables that impact video conferencing between the clinic and patients and caregivers at home. Experimental research is needed to determine if using mobile device videoconferencing is more effective than using telephone (audio only) support in caring for patients at home. The focus of this descriptive study was to determine if patients and caregivers intend to use mobile device videoconferencing for remote mechanically-ventilated patient management, assuming the service was implemented in the Michigan Medicine hospital system.

The goal of this proposed descriptive research was to identify and characterize several key factors about the approximately 670 mechanically-ventilated patients supported by the Assisted Ventilation Clinic. Implementing a remote home mechanically-ventilated patient program that supports the use of mobile devices using videoconferencing for remote ventilated patients depends greatly upon the attitudes, experience, and mobile device pervasiveness among these patients and their caregivers. For example, supporting a videoconferencing program when only 5% of the patients have access to mobile devices would greatly limit a remote mechanically-ventilated patient management program using mobile devices, while a patient population with 80% having access to mobile devices might allow it to flourish. Constructs such as *perceived ease of use*, *perceived usefulness*, and *intent to use* are also critical factors that could impact the rollout of a program such as this. The purpose of this descriptive study was to sample the approximately 670 Assisted Ventilation Clinic mechanically-ventilated patients using a questionnaire to determine the following:

- their access to and types of mobile devices;
- their attitudes toward telemedicine;
- their age, gender, and other demographics;
- their understanding of the potential of videoconferencing in remote ventilated patient care;
- their conditions, time on a ventilator, and distance from advanced care;
- their perceptions of the usefulness and ease of use; and ultimately,
- their intent to actually use mobile devices in their care.

An analysis of the data gathered from this study provided insight as to whether adding mobile device videoconferencing to telephone-only support (or usual care) was desirable from the patients' and caregivers' points of view. From a larger policy perspective, the patients' attitudes, experience, access, and perception could make or break a proposed remote home mechanically-ventilated patient management program using mobile devices. The goal of this descriptive study was to discover key characteristics of the Assisted Ventilation Clinic mechanically-ventilated patient population to determine if remote home mechanically-ventilated patient management was feasible based upon patient perceptions, attitudes, and access to mobile devices.

Statement of the Problem

The extent or level of Assisted Ventilation Clinic patient and caregiver readiness, which includes *own/access* to mobile devices, *perceived usefulness, perceived ease of use*, and *intent to use* mobile devices for videoconferencing in remote ventilated patient management, was unknown.

Among the approximately 670 mechanically-ventilated patients (and caregivers) supported and cared for by the Michigan Medicine adult Assisted Ventilation Clinic, it was unknown how many patients and caregivers owned mobile devices or have access to them through their caregivers or family members, and furthermore, their level of *intent to use* them for telemedicine videoconferencing in remote ventilated patient management was also unknown. Further, the patient and/or caregiver perceptions regarding the perceived value of using mobile devices in remote home mechanically-ventilated patient management was also unknown.

Nature and Significance of the Problem

Often obscured by the statistical and clinical aspects of spinal cord injuries and neuromuscular disorders is the heavy emotional impact and burden of care experienced by the caregivers, family, friends, and of course the patients themselves. Occasionally, a public window is opened into the lives of those suffering from a spinal cord injury or neuromuscular disorder, which provides a close-up view of the personal suffering associated with these conditions. Actor Christopher Reeve was perpetually captured in the mind’s eye as the invincible Superman through movies, but in real life had become totally dependent upon others for survival due to severe paralyzing spinal cord injury resulting from an equestrian fall. Likewise, Stephen Hawking, considered one of the most brilliant theoretical physicists since Einstein, fell victim to the power of a motor neuron neuromuscular disorder, ALS or Lou Gehrig's disease (Hawking, 2016). Although these are only two high-profile cases of spinal cord injury and neuromuscular disease that were exposed through the media, we need to consider the significance of multiplying the suffering of these two cases by the millions of cases globally where the victims are not nearly as well supported physically, socially, emotionally, and financially.

The Michigan Medicine investigation of improving remote ventilated patient management using mobile devices began in 2014 in a joint meeting between staff of the Adult Assisted Ventilation Clinic (of the Department of Internal Medicine, Division of Pulmonary Clinic of Michigan Medicine) and the Virtual Health group supporting telemedicine. The Assisted Ventilation Clinic provides comprehensive care in a single location by integrating a nurse practitioner (NP—care coordination), pulmonary and critical care specialist physicians (lung problem management), physical medicine and rehabilitation specialist physicians (general rehabilitation care and some primary care needs), respiratory therapists (RTs—ventilator management), dietitian (nutrition), and social workers into a single support service to manage the diverse needs of patients with neuromuscular diseases and spinal cord injuries. Patients can come to the clinic for switching out their tracheostomy tube as needed, wound care, trachea assessment, adjusting ventilator settings, and adjusting cough assist (mucus clearing or insufflator-exsufflator) devices (e.g., CoughAssist T70). In some cases, an RT clinician has traveled to the patient's home to reconcile and record medications, educate the patient or caregivers, and assess the patient (AVC1, 2016). An additional service provided by the Assisted Ventilation Clinic was telephone-only support—this allows clinicians to remotely support and trouble shoot ventilator, cough assist, and patient problems that may arise at home. However, telephone (audio)-only support has limitations such as delay and uncertainty (Smith et al., 2014).

To overcome the delay and uncertainty of telephone-only support, the Assisted Ventilation Clinic and Virtual Health groups proposed using information and communications technology (ICT) to allow telemedicine or videoconferencing between the clinic and the patient at home. To simulate the patient at home, a room was setup inside the Assisted Ventilation Clinic with a mechanical ventilator configuration, which allowed experimentation with a variety of ICT, such as laptops, smartphones, tablets, and a variety of videoconferencing applications to determine what types of technology were most effective. Due to the need to move around in the patient's environment, mobile devices were most effective while laptops were bulky and more difficult to position and move. In the clinic, the NP and RT preferred to use an iPad Air tablet, which gave them the flexibility to simply go to any available room in the clinic to perform remote home mechanically-ventilated patient management (Smith et al., 2014). Additional testing was performed with three actual patients in their homes to test the feasibility of using patient-owned mobile devices, which included an iPhone 4S, an iPad Mini, an iPhone 5S, and an Android smartphone. Based on basic experimentation, the potential for using mobile devices for remote home mechanically-ventilated patient management seemed feasible. However, additional qualitative and experimental research is required to establish conclusive evidence of the advantages of using mobile device videoconferencing versus telephone-only support.

Understanding the characteristics, perceptions, attitudes, and capabilities of the patient and caregiver population was pivotal to moving a videoconferencing telemedicine program forward. Implementation of this program relies upon patients and caregivers owning or having access mobile devices, being experienced users, and their *intent to use* those mobile devices and videoconferencing for remote patient management. Active participation by the providers, patients, caregivers, nurses, and family is essential for the implementation of remote home mechanically-ventilated patient management.

A discussion of why this study is unique and what it contributes to the existing body of knowledge is presented next. The many different facets of this study are depicted in Figure 1; although most of the facets examined alone are not unique, when integrated together they comprise an approach to remote ventilated patient management that is unique. In Chapter 2, many of these facets are reviewed in more detail through the literature review as they relate to the management of mechanically-ventilated patients. At this point, a review of the history of mechanical ventilation helps pave the path in understanding the current state of telemedicine in remote home mechanically-ventilated patient management and describe the latest relevant research.

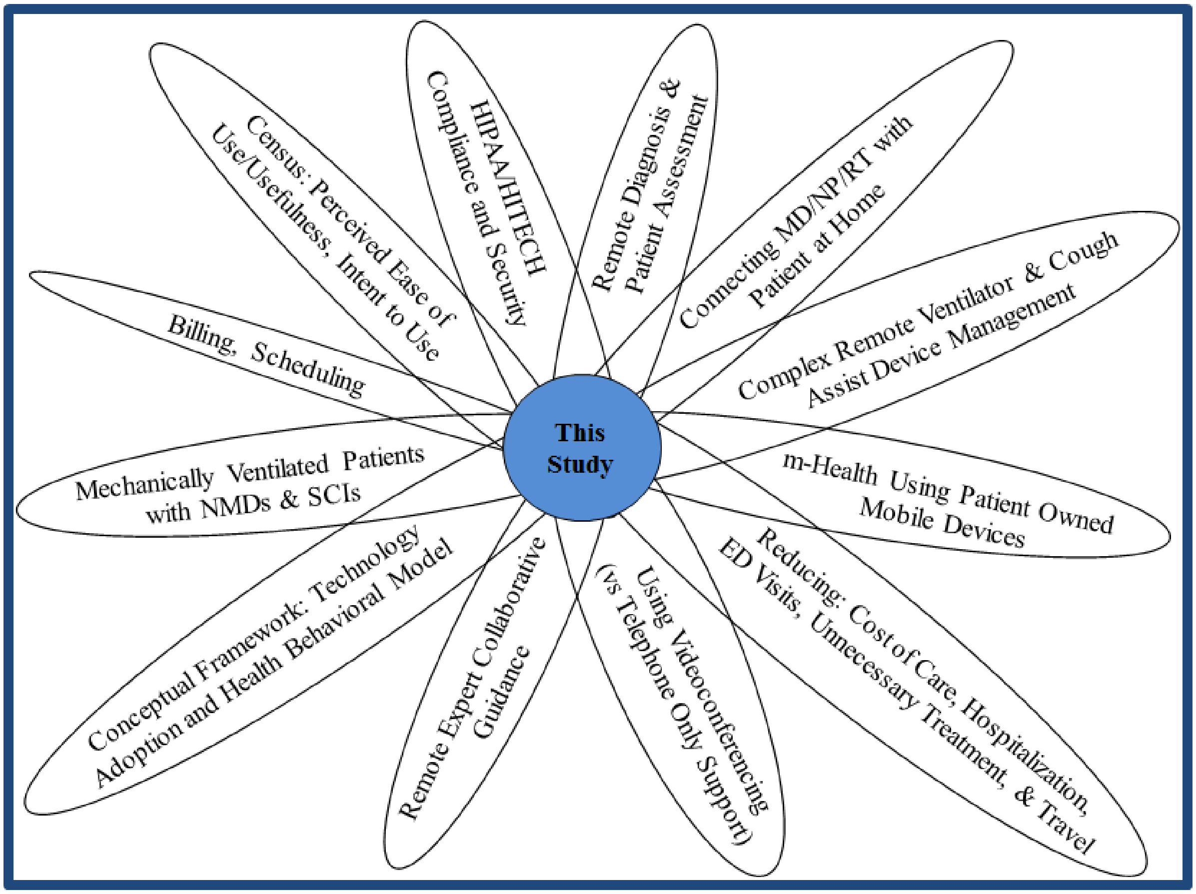


Figure 1. This descriptive study integrates multiple facets of remote home mechanically-ventilated patient management.

In the 16th century, Vesalius first recognized the concept of artificial respiration (Slutsky, 1993). However, mechanical ventilation wasn't developed and used extensively until the period of the 1900s to 1950s when it was used to treat poliomyelitis. Initially, negative pressure iron lungs (also called body or tank ventilators) were used to manage those with severe respiratory dysfunction. As the patient's condition improved, respiratory support may progress to rocking beds or jacket ventilators. In the 1960s, positive pressure mechanical ventilators began to be used along with invasive tracheostomies to provide respiration. Improvement in masks and mouth pieces promoted the extensive use of non-invasive positive pressure mechanical ventilation for those with less severe respiratory conditions such as sleep apnea or early stage diseases (Perrin, Unterborn, Ambrosia, & Hill, 2004).

Care of the mechanically-ventilated patient is quite expensive, which has promoted a shift from keeping ventilated patients in the hospital or ICU to transferring them to the home environment for long-term ventilation. Hospital costs for a mechanically-ventilated (MV) patient care are $21,570 per month in-hospital versus $7,050 per month in-home (a $14,520 savings per month). An enhanced quality of life and integration into family and community are side benefits of home MV. Risks associated with non-invasive MV are lower than invasive MV (where the patient is totally dependent on the ventilator for breathing through a tube inserted through a tracheostomy). This descriptive study focuses on all approximately 670 mechanically-ventilated patients supported by the Assisted Ventilation Clinic—approximately one third are receiving intubated or invasive mechanical ventilation (where a ventilator tube is inserted into the trachea through a stoma to create a port into the lungs to support respiration) or non-invasive mechanical ventilation that employs a breathing mask. Complications that can arise from invasive MV can be more severe and life threatening than non-invasive MV that might be used in supporting sleep apnea or optional assistive breathing (King, 2012).

Although costs are reduced and quality of life is improved for home-ventilated patients, it also creates risks, challenges, and an increased burden on both clinical staff and remote in-home caregivers. This was best summarized by Boroughs and Dougherty (2012) in their paper "Decreasing Accidental Mortality of Ventilator-Dependent Children at Home: A Call to Action": "mechanical ventilation is a high-stake, high-risk intervention" (p. 104). Clinicians can be separated by significant distance or time and limited visibility into the home setting while, on the other hand, in-home caregivers shoulder the weight of the ventilated patient's life resting in their care (Boroughs & Dougherty, 2012).

Caregiver burnout and the need for training also need to be mentioned in caring for MV patients. Boroughs and Dougherty (2012) lists inadequate training, clinician's lacking vigilance, and incorrect response as major causes of preventable deaths of MV children. The level of caregiver burden is directly related to the severity of the underlying disease, distance from the hospital, patient having a tracheostomy, and needing to seek emergency care (Vitacca et al., 2007a). There seems to be a correlation with ALS patients respiratory issues increasing with caregiver distress, which led Pagini et al. (2012) to hypothesize that the better the caregiver does, the better the ALS patient does. A Korean study points to findings that indicate more community-based support is needed for ALS family caregivers who experience a low quality of life and high burden in caring for their ALS patient (Kim & Kim, 2014).

Things can and do go wrong. Failed ventilators, incorrect settings, infections, bleeding, mucus plugging or buildup, disregard for excessive alarms, tube obstructions, sepsis, and significant time or distance from a clinic or emergency department can all lead to patient death (King, 2012). To counter these life-threatening conditions, many clinics have instituted telephone support to assist the in-home caregivers in managing the MV patient. Six studies by Vitacca et al. (2006, 2007a, 2007b, 2009, 2010, & 2012) focused on telephone support and included a nurse-led telephone support pilot study (Vitacca et al., 2006), telephone assistance in weaning patients from MV at home (Vitacca et al., 2007b), an RCT investigating ALS patient tele-assistance (Vitacca et al., 2009), providing at home cough assistance for ALS patients (Vitacca et al., 2010), and a tele-assistance study of long-term activity and costs in caring for ALS patients at home (Vitacca et al., 2012). Primary goals were reducing costs, improving quality of life, supporting caregivers, reducing hospital length of stay, reducing readmits, and reducing visits to the emergency department. The present descriptive study expands on using remote telephone-only support by investigating using mobile device videoconferencing as an alternative support option in remote home mechanically-ventilated patient management.

Unfortunately, telephone (audio only) support has limitations. Some challenging examples include a caregiver trying to describe ventilator screens, the color or viscosity of sputum, or the characteristics of the stoma or wound—the clinician's perception of the caregiver's description don't always match in actual practice according to Assisted Ventilation Clinic clinicians. Also, when the clinician (RT or NP) is guiding the caregiver in adjusting settings of the ventilator or cough assist machine, it is unclear if the remote caregiver is accurately performing what is being instructed? Ventilators and MV patients can be complex to manage. A window into the patient's environment is needed.

As a result, in 1997, several Japanese doctors at the National Children's Hospital in Tokyo initiated a prospective study using ISDN-based video phones to help care for MV children (n = 10) at home. When comparing with the previous 6 months, results were positive with a reduction in physician house calls, hospital visits and admissions, and a reduction in the overall amount physician time spent caring for the mechanically-ventilated children (Miyasaka, Suzuki, Sakai, & Kondo, 1997). Research using videoconferencing between 1997 and 2014 is sparse to non-existent. However, the only study investigating videoconferencing in caring for remote mechanically-ventilated patients was a 2014 study (n = 14) where families with a computer and webcam were provided free software to communicate about their in-home MV child (Casavant, McManus, Parsons, Zurakowski, & Graham, 2014).

Although this was a small study, the results indicated that videoconferencing was useful in providing support, managing fragile MV patients at home, supporting decision-making, reducing clinical and emergency department visits, and potentially hospital admissions.

The Casavant et al. (2014) pilot study provides a springboard for this descriptive research proposal. It demonstrated that videoconferencing helps in decision-making for fragile MV patients and increases the family/caregiver confidence in their clinical management, and the study indicated that live images provide clarity beyond telephone description of fatigue, breathing effort, or rash severity. One of the key questions involves what technologies are available in the patient's home for videoconferencing? Casavant et al. (2014) further propose that videoconferencing may be beneficial for many other diseases where patients and clinicians are separated by distance, lack of mobility, those at high-risk, or those requiring frequent contact with clinicians. Casavant et al. (2014) also mentioned using Vidyo and mobile devices, but it was unclear if they were actually used in their study.

Telemedicine in the ICU often utilizes expensive equipment with remotely-controlled cameras that allow the remote intensivist or specialist to pan, tilt, and zoom a camera in to assess the patient's pupils, breathing patterns, skin color, IV bag labels or ventilator settings (Goran, 2010). According to a recent paper by Bell et al. (2016), approximately 10% of the ICU (Intensive Care Unit) hospital beds in the U.S. had some form of remote ICU telemedicine continuous monitoring and with many having additional types of remote care. They indicate that many studies provide evidence of cost savings and mortality reduction in adult ICUs when remote critical care specialists use telemedicine to continuously monitor patients remotely. Although the focus of their paper was on the neonate and pediatric ICU, they state that there are no known published research papers on the respiratory therapist's role in the telemedicine ICU (Bell et al., 2016). They point out that there appears to be no research focusing on RT ventilator management in the tele-ICU. After an extensive literature search, the researchers concluded that there also appears to be no research focusing on using patient-owned mobile devices in the mechanically-ventilated patients at home with a RT and NP in a remote clinic performing remote home mechanically-ventilated patient management.

Most ICUs use expensive ICT equipment to establish the connectivity between the patient in the ICU and the remote critical care specialist. Utilized in the Bell et al. (2016) research mentioned previously, a $35K Tandberg/Cisco Intern Cart system was used in the patient's clinical room while the remote respiratory therapist was using a desktop or laptop with free Vidyo software downloaded onto it. They also mention that to create a complete H.323 compatible Vidyo system for videoconferencing would cost between $100K and $500K.

There are a variety of similarities and differences between this research proposal and the Bell et al. (2016) research mentioned above. Although both are trying to connect a respiratory therapist to the remote patient, our setting endpoints are from the clinic to the patient at home rather than between two clinics. Rather than using expensive videoconferencing systems at each endpoint, our study uses an iPad Air at the clinic endpoint and patient-owned or accessible mobile devices in the patient's home. In the Bell et al. (2016) case, they used a SERVO-I ventilator while the Assisted Ventilation Clinic must support multiple types of ventilators, such as the LTV 950 or Trilogy 100 (Trilogy, 2014). The general framework for the Bell et al. (2016) study was to randomly assign one of 16 RTs to a remote or telemedicine location while another randomly selected RT was assigned to be with the patient face-to-face. A total of 40 assessments were made concurrently, one remote assessment followed immediately by a face-to-face assessment of the same patient—specifically 20 remote telemedicine assessments were made while 20 face-to-face assessments were made on 11 patients (6 in the pediatric ICU and 5 in the neonatal ICU). Of particular value in this study are the parameters measured, the demographic data, and the parameters that clinicians would like to measure in the future. Demographic variables included age, sex, ethnicity, weight, diagnosis, and intubation time. Ventilator parameters included PEEP, breathing rate, inspiratory time to expiratory time ratio, mean airway pressure, pressure control, and F_{IO_2}. Patient parameters included minute ventilation, presence of patient triggered breaths, tidal volume, oxygen saturation, and the need for ventilator support or for suctioning (based upon the RT's assessment of pressure readings, ventilator waveforms, and tidal volume). Post-study, the respiratory therapists mentioned several parameters they would like to measure in future studies: endotracheal tube cuff pressure, review of ventilator alarms, and an auscultation exam (using a standard/telemedicine stethoscope). Some additional parameters they suggested may be helpful to measure included pressure-volume loops, chest rise, ventilator synchrony or patient/ventilator asynchrony, ventilation tube condensation, and auto-PEEP presence. Characterizing and identifying the most valuable mechanical ventilation parameters are useful in constructing the details of follow-on experimental research.

Conceptual Framework of This Descriptive Research

The significance, integration of unique facets of this present study, the history of mechanical ventilation, and a snapshot of the latest state of research on remote ventilated patient management has been revealed above. The next topic is the conceptual framework that was used for this study. The core of this study and pivotal to the actual implementation of remote home mechanically-ventilated patent management using mobile devices are the perceptions, mobile device capabilities, and attitudes of the approximately 670 ventilated patients supported by the Assisted Ventilation Clinic and ultimately their *intent to use* this new capability. Depending upon perceptions and *intent to use*, understanding the mechanically-ventilated patient population's rejecting or embracing telemedicine using mobile devices will help providers decide which sub-populations supported by the adult Assisted Ventilation Clinic will want to use this technology.

Evaluating and analyzing technology acceptance has been a common topic of research for many years, finding its origination in Everett M. Roger's 1983 *Diffusion of Innovations* including the technology acceptance life cycle and Davis's (1989) technology acceptance model (TAM). How, when, and why people embrace new and innovative technology continues to be a vital area of research in this technological world. Likewise, in this study, are the approximately 670 Assisted Ventilation Clinic patients ready to adopt and use remote home mechanically-ventilated patient management using mobile devices in their care? The Patient *intent to use* conceptual framework based on Davis's (1989) TAM in Figure 2 is built upon Davis's TAM model and captures the essence of what must be determined to know the potential acceptance of mobile device videoconferencing in remote ventilated patient management. Although each category has many subcomponents, the key variables that must be determined relative to the approximately 670 ventilated patients are (a) their *perceived usefulness* of mobile devices and videoconferencing in remote ventilated patient management, (b) their *perceived ease of use* of the technology, and (c) their *intent to use* or accept mobile device videoconferencing—without patient and caregiver buy-in and access to mobile devices, a large barrier to acceptance is created. Ultimately, these three variable clusters lead to the ultimate question, do the patients intend to use mobile device videoconferencing in their remote care?

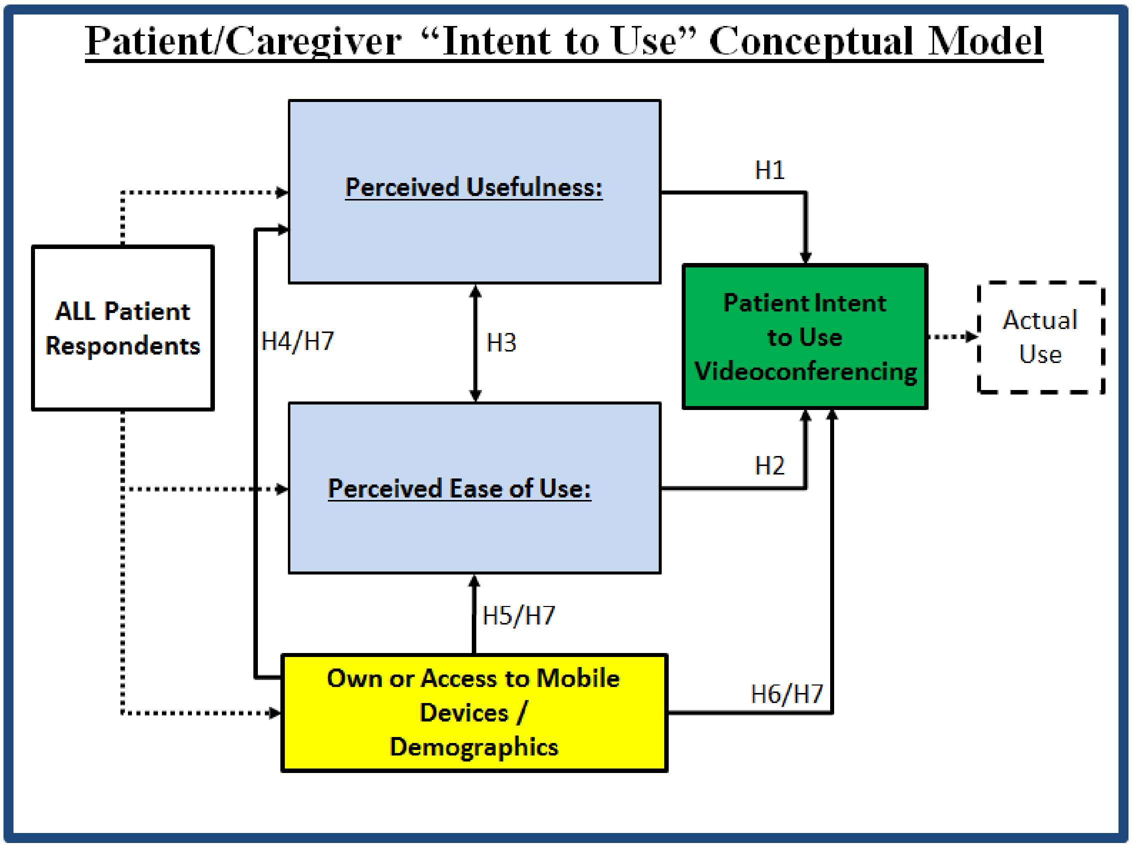


Figure 2. Patient *intent to use* conceptual framework based on Davis's (1989) TAM.

The acceptance model was developed in more detail in the literature review in Chapter 2 (where other acceptance and health behavioral models were examined) and in Chapter 3 as a part of the questionnaire development section.

Purpose and Objective of the Research

The purpose of this descriptive study was to capture a representative sample of the mobile device access profiles of the approximately 670 mechanically-ventilated patients supported by the Assisted Ventilation Clinic and to measure their *perceived ease of use*, *perceived usefulness*, and their *intent to use* mobile devices for remote home mechanically-ventilated patient management. An analysis of the resulting data helped in the development of telemedicine policy based upon the extent of patient-owned mobile devices that could be used in remote patient care at home. Ultimately, the patients' perceptions and attitudes regarding their *intent to use* mobile devices in their care can make or break a telemedicine program.

The objectives of this descriptive research can be summarized in the following statements:

- To determine the extent of patient access or ownership (*own/access)* of Apple and Android mobile devices,
- To determine the patients' perceptions regarding the *perceived usefulness* of mobile devices in remote care,
- To determine the patients' perceptions regarding the *perceived ease of use* of mobile devices in remote care,
- To determine the patients' level of expertise in using mobile devices,
- To determine the degree to which they intend to use mobile device videoconferencing for remote mechanically-ventilated patient management, and
- To identify any relationships between *perceived ease of use*, *perceived usefulness*, their sub-constructs, *own/access* to mobile devices, *intent to use*, and *demographic* variables.

Research Questions

Each of the following research questions was addressed based on the self-reported perceptions of mechanically-ventilated patients or their caregivers supported by the Michigan Medicine adult Assisted Ventilation Clinic.

Question #1: What was the relationship between *perceived usefulness* and *intent to use* mobile device videoconferencing for remote ventilated patient management?

Question #2: What was the relationship between *perceived ease of use* and *intent to use* mobile device videoconferencing for remote ventilated patient management?

Question #3: What was the relationship between *perceived usefulness* and *perceived ease of use* in mobile device videoconferencing for remote ventilated patient management?

Question #4: What was the relationship between *own/access* to mobile devices and *perceived usefulness* in mobile device videoconferencing for remote ventilated patient management?

Question #5: What was the relationship between *own/access* to mobile devices and *perceived ease of use* mobile device videoconferencing for remote ventilated patient management?

Question #6: What was the relationship between *own/access* to mobile devices and *intent to use* mobile device videoconferencing for remote ventilated patient management?

Question #7: What was the relationship between demographics and *intent to use* mobile device videoconferencing for remote mechanically-ventilated patient management?

Null Hypotheses

The following are null hypotheses related to the patient *intent to use* conceptual framework depicted in Figure 2. These null hypotheses were evaluated using a $p = .05$ significance level and are described in more detail in Chapter 3. For definitions of the corresponding alternative hypotheses, please refer to Appendix A.

Null Hypothesis $H1_0$: There is no significant relationship between *perceived usefulness* and patient or caregiver *intent to use* mobile device videoconferencing.

Null Hypothesis $H2_0$: There is no significant relationship between *perceived ease of use* and patient or caregiver *intent to use* mobile device videoconferencing.

Null Hypothesis $H3_0$: There is no significant relationship between *perceived usefulness* and patient or caregiver *perceived ease of use* of mobile device videoconferencing.

Null Hypothesis $H4_0$: There is no significant relationship between *own/access* to mobile devices and patient or caregiver *perceived usefulness* of mobile device videoconferencing.

Null Hypothesis $H5_0$: There is no significant relationship between *own/access* to mobile devices and patient or caregiver *perceived ease of use* of mobile device videoconferencing.

Null Hypothesis $H6_0$: There is no significant relationship between *own/access* to mobile devices and patient or caregiver *intent to use* mobile device videoconferencing.

Null Hypotheses $H7.1_0$ to $H7.14_0$: There is no significant relationship between demographics and patient or caregiver *intent to use* mobile device videoconferencing.

Limitations and Delimitations

The following limitations are acknowledged for the purposes of this study:

- Participation in this research requires informed consent by the patient.
- Demographics of the approximately 670 Assisted Ventilation Clinic patients are fixed for this population. Demographics include the following types of data: age, diagnosis, hours per day on ventilator, distance from the nearest emergency department, distance from the Assisted Ventilation Clinic at Michigan Medicine, mobile device access or ownership, and other factors.

The following delimitations were selected to provide useful parameters to help appropriately focus the study in addition to help make this study feasible:

- Acceptable mobile device options for this study are limited to Apple and Android mobile devices in the patients' homes and an iPad Air in the Assisted Ventilation Clinic.
- Only mobile devices owned or accessible by patients and caregivers are acceptable access options. Mobile devices may be patient owned OR caregiver owned OR family member owned mobile devices and must be available for use between 8 am–5 pm Monday through Friday.

The questionnaire (including pictures depicting telemedicine activities, 14 demographic questions, and 24 measurement items) can be delivered to the patient and/or caregivers several ways: the questionnaire can be completed (a) using a paper version in the clinic, (b) using an iPad and a Qualtrics link in the clinic, (c) using their computer or mobile device at home after receiving a Qualtrics link email link, (d) completing a paper version at home and returning it in a postage paid self-addressed envelope, (e) and as a last resort, over the phone interview completion of the questionnaire. All these modes eventually involve completing a Qualtrics questionnaire, which provides the questions and collects the responses into a PHI compliant database.

Definition of Terms or Acronyms

ALS: amyotrophic lateral sclerosis

Alternate Hypothesis: the hypothesis that you theorize or are trying to prove is true—written as HX_A, where X represents the hypothesis number (e.g., $H3_A$)

AVC: Assisted Ventilation Clinic in the Michigan Medicine health system

Bulbar: muscles of the mouth and throat responsible for speech and swallowing

Caregiver: a general term applying to nurse, home health aide, or family member who provides care for the mechanically-ventilated patient at home or while travelling

Clinician: a physician, nurse, psychologist, respiratory therapist or other healthcare provider with a degree or certificate

Cough Assist Device: a mechanical insufflator and exsufflator that simulates a cough in patients with neuromuscular weakness, bringing sputum up to the large airways where it can be cleared out via suction (e.g., Respironic's Cough Assist T70). It can be used with a mask or via a tracheostomy tube.

ED: emergency department

DM: Dermatomyositis

DMD: Duchenne muscular dystrophy

HipaaChat: a video calling HIPAA/HITECH compliant application used on Apple and Android smartphones and tablets

ICT: information and communications technology

MD: medical doctor

Mechanical Ventilator: an electromechanical machine that inflates and deflates the patient's lungs.

Michigan Medicine: formerly named University of Michigan Health System (UMHS)

Mobile Devices: smartphones and tablets (e.g., Apple iPhone or iPad, Android smartphone or tablet, or Microsoft smartphone)

NMD: neuromuscular disease

NP: nurse practitioner

Null Hypothesis: the negated position of the alternate hypothesis, stating there is no difference or relationship between populations, denoted HX_0, (e.g., $H3_0$ for null hypothesis 3)

PICU: pediatric intensive care unit

RT: respiratory therapist

SCI: spinal cord injury

Smartphone: a hand-held mobile device with an LCD, cameras in front and back, a microphone and speaker, the ability to run downloadable applications, and videoconferencing.

Tetraplegia: also called quadriplegia—paralysis of all four limbs with a loss of motor and/or sensory function in the cervical spinal segments is impaired or lost due to damage to that part of the spinal cord, resulting in impaired function in the upper limbs, lower limbs, trunk, and pelvic organs. This term does not include conditions due to brachial plexus lesions or to injuries of peripheral nerves outside the spinal canal (Medict, 2017).

Tracheostomy: A surgical procedure that creates an opening into the trachea, a tracheostomy tube is then inserted that may or may not have a cuff on it.

Videoconferencing: visual and auditory communication between two or more parties over a cellular or Internet network—also called video calling.

Assumptions

The following are assumptions made for the purposes of this study.

Assumption 1: Patient and caregivers with access to mobile devices know how to use their mobile devices for communication but may not necessarily know how to use them for videoconferencing.

Assumption 2: Patients and caregivers with limited previous knowledge can be trained to use mobile devices in videoconferencing remote ventilated patient management.

Assumption 3: Caregivers can be remotely guided to adjust settings and resolve equipment problems using videoconferencing.

Assumption 4: Patients and caregivers with access to mobile devices are capable of downloading and configuring videoconferencing applications (with help if needed) and are able to participate in the videoconferences using their mobile devices.

Assumption 5: Caregivers and family will provide support for patients with quadriplegia and tetraplegia, such as holding phones, adjusting equipment settings, adjusting lighting, and directing and revealing wounds or tracheostomy for viewing.

Chapter 2: Background and Review of the Literature

Introduction

Remote ventilated patient management comprises many facets that by themselves are not particularly unique. However, when integrated together, they potentially provide a new and innovative way to remotely care for mechanically-ventilated patients. To capture the full breadth and depth of implementing remote ventilated patient management using mobile devices, this section examines the background and research literature by decomposing remote home mechanically-ventilated patient management into nine separate areas related to the study. The areas to be addressed include the following:

1. m-Health,
2. Neuromuscular Disorders and Spinal Cord Injuries,
3. Cost of Remote Ventilated Patient Management,
4. Complexity of Mechanical Ventilators,
5. The Adult Assisted Ventilation Clinic—Clinical Quality Improvement,
6. Limitations of Telephone-Only Support vs. Benefits of Using Mobile Devices,
7. Current State of Remote Ventilated Patient Management Research,
8. Remote Expert Collaborative Guidance, and
9. Technology Acceptance and Health Behavior Models—Measuring *Intent to Use.*

m-Health

Using mobile devices, such as smart-phones and tablets, in healthcare was not a new concept. The term m-Health has appeared in the research literature beginning in 2003 (Bashshur, Shannon, Krupinski, & Grigsby, 2011). There are a variety of terms used to describe the use of information and communication technology (ICT) when applied in healthcare. A variety of common terms used include telemedicine, telehealth, eHealth, m-Health, and many more. There was clear dis-unity on these healthcare/technology terms. For example, a literature search on the terms *eHealth*, *e-Health*, or *electronic health* between 1966 and 2004 came up with 51 unique definitions for the terms (Oh, Rizo, Enkin, & Jadad, 2005). The term m-Health was first used by Istepanian and Lacal in their 2003 paper describing the use of mobile telecommunications in healthcare although reference to the use of mobile telecommunications in healthcare or using PDAs in healthcare dates back to 1999 (Istepanian & Lacal, 2003). As technology evolves, so does the concept of what m-Health entails in practice, which tends to create a genetic type definition drift over time to include new technological capabilities. A prime example of the breadth of m-Health was captured by Claudia Tessier and Peter Waegemann's presentation on the *12 Clusters of m-Health* mentioned in a book by Anastasia Moumtzoglou (2016). They describe 12 major application clusters into which m-Health applications can be categorized. These include patient communication, access to web-based resources, point-of-care documentation, disease management, education programs and telemedicine, professional communication, administrative applications, financial applications, public health, pharma/clinical trials, and body area networks (Moumtzoglou, 2016). However, remote expert collaborative guidance, which is discussed in a following section, does not fall specifically into one of these 12 categories. For this study, the definition of m-Health includes using Apple and Android smartphones and tablets, HIPAA/HITECH complaint videoconferencing applications, wireless communications (which can be either cellular or WiFi—and are used specifically for remote home ventilated patient management and patient diagnosis), and RT/NP caregiver guidance.

A presentation by Waegemann (2009) expanded on the 12 clusters of m-Health. Each cluster is described briefly here: (a) patient communications includes accessing calendars, resources, reminders, text messaging, and education; (b) access to web-based resources includes using mobile devices to access Internet-based health resources; (c) point-of-care documentation for clinicians and physicians includes accessing medical records with health history and mobile data transmission; (d) disease management includes mobile applications that aid patients in managing chronic conditions such as asthma, dermatology, diabetes, smoking cessation, and so on; (e) point-of-care education includes education applications such as short information messages; (f) professional communication includes using mobile devices for consultation between hospital workers, technicians, pharmacists and other healthcare workers; (g) administrative applications include applications to improve workflow efficiency of local and remote clinicians; (h) financial applications include helping patients manage financials and insurance; (i) ambulance/EMS includes providing the first responders with EHR information and patient history; (j) public health includes using mobile devices for disease tracking, providing epidemic or outbreak information, alerts and management of bioterrorism; (k) research includes using mobile devices for data collection; and (l) body area network (BAN) applications for sensor data and biometric collection and transmission back to health data centers/EHRs for storage and analysis (Waegemann, 2009).

A 2013 article in *Modern Healthcare* stated that of the 43,700 healthcare or applications labeled medical in Apple's iTunes App Store, there were only 54% that were actually medical apps; 69% were targeting patients and consumers and 31% were intended for clinician use. The article also cites the Robert Wood Johnson Foundation policy brief published in *Health Affairs*, where experts predict a 25% annual increase in mobile healthcare apps into the foreseeable future. They also predict that 3.4 billion healthcare app users (consumers, patients, and clinicians) will download an application by 2018 (Modern Healthcare, 2013). Demonstrating the rapid growth of health-related apps, a September 2015 article in *Healthcare IT News* stated that 165,000 applications identified for healthcare were available for download. However, they also describe a free-for-all in how apps are chosen, evaluated, and used, with patients often going with those that are most popular, and in addition, they also noted that of 26,000 apps evaluated, 36 apps comprised 50% of the downloads (Healthcare IT, 2015). In summary, thousands of healthcare apps are being created each year, but very few of those are dominating mainstream usage with only a very few becoming the most popular. Clearly, m-Health is an active area of healthcare innovation with a large market desiring to leverage mobile devices in healthcare.

A report by *IMS Health* (IMS, 2016) titled "Patient Acceptance of m-Health" had similar findings to the *HealthIT* report mentioned earlier. Thirty-six apps accounted for half of all downloads, while 40% of all applications have less than 5,000 downloads. Application areas include information, instructions, medical records, display, guidance, reminders and alerts, and communication. Ninety percent of health apps are free to download. M-Health apps are used by healthcare providers/insurance (2%), medication reminders and information (6%), women's health and pregnancy (7%), disease specific (9%), for diet and nutrition (12%), for lifestyle and stress (17%), for fitness (36%), and other categories (11%; IMS, 2016). Many 2015 m-Health applications are developed for specific diseases such as mental health (29%), diabetes (15%), heart and circulatory diseases (10%), musculoskeletal diseases (7%), nervous system diseases (6%), and other diseases (33%; IMS, 2016). Some of the barriers that are inhibiting the acceptance of m-Health applications include limited systematic integration into health systems, reimbursement challenges, patient access gaps, data privacy and security issues, and lack of evidence (IMS, 2016).

Surely with so many medical applications, there should be some related to mechanical ventilation and caring for ventilated patients. However, examining the Apple iTunes available medical applications, two relevant applications were found: (a) Tracheostoma, an information video in German; and (b) Ventilation Perfusion Matching, an educational video for medical students. No other applications were found for patients, caregivers, or clinicians related to remote ventilated patient management (iTunes, 2016). One reason for the absence of ventilation related apps could be FDA regulations over life critical applications and clearly mismanagement of ventilators can result in death.

The FDA does not mandate and regulate how physicians and clinicians practice medicine, which is the responsibility of licensing agencies. This does not preclude clinicians from using non-medically marketed applications in the practice of medical care. A telephone is not a medically-regulated device; however, clinicians communicate with patients using telephones to make healthcare-related decisions. Likewise, videoconferencing applications are not regulated by the FDA although many healthcare institutions insist on the videoconferencing provider signing a business associate agreement (BAA) to more fully satisfy HIPAA/HITECH PHI compliance requirements.

A critical aspect of this descriptive study was the assumption of using patient-owned or accessible mobile devices, which limits costs to Michigan Medicine and leverages a frequently upgraded mobile device infrastructure that can be leveraged for remote patient management. Using only the standard sensors in mobile devices (e.g., image sensors or cameras, microphones, accelerometers, and GPS), diagnostic data is limited (although add-on peripherals are being developed). Also, lighting can impact color, which in turn may limit detection of cyanosis or mucus/sputum color and make it difficult to determine if an emergency department visit is appropriate. A key aspect of diagnosis rests upon the clinicians (MD, NP, and RT) past perception of a patient baseline when they were healthy and considered normal. Using videoconferencing, they can compare the patient's current health with the patient baseline to make a decision. The clinicians make the final decision—if there is not sufficient information to make a diagnosis, they can recommend that patient go to the emergency department, come to the clinic, or to wait to see how the condition develops. Unlike normal patients at home, ventilated patients have a caregiver (e.g., nurse or family member) who can take vitals and describe or clarify data that may not be available through videoconferencing alone.

Mobile device availability and capabilities continue to evolve. There are many medical mobile device attachments that may become more readily available in the patient's home as device's cost decreases over time as a result of increased sales volumes. Examples of mobile device attachments, as shown in Figure 3, allow clinicians to remotely diagnose patients' conditions more accurately. Some mobile device attachments which currently exist include: retina imaging (ophthalmoscope), ultrasound imaging, ECG capture, auscultation (stethoscope), ear examination (otoscope), and skin examination (dermoscope). Mobile device availability and usage will only increase; a 2014 U.N. study determined that of the world's 7 billion people, 6 billion have access to mobile phones while only 4.5 billion have access to working toilets (PhonesThrones, 2014).

Significant research is focusing on m-Health applications. A May 3, 2016, broad search of Google Scholar using the terms *m-Health* or *mHealth* yielded a result of 34,200 references. Even the selective and peer reviewed PubMed website (PubMed, 2016) of the U.S. National Library of Medicine/National Institutes of Health yielded a total of 24,171 *m-Health* or *mHealth* search results. Clearly, mobile health devices and applications are becoming part of mainstream healthcare and research.

Figure 3. Specialized mobile device attachments for remote patient telemedicine care.

By using mobile devices in remote home mechanically-ventilated patient management, the Michigan Medicine Assisted Ventilation Clinic is practicing m-Health. At this point, the review of the literature delves into the underlying conditions that cause the need for mechanical ventilation, neuromuscular disorders and spinal cord injuries.

Neuromuscular Disorders and Spinal Cord Injuries

A discussion of neuromuscular diseases or disorders and spinal cord injuries is included to describe the types, symptoms, causes, progression, and conditions that require mechanical ventilation. An understanding of neuromuscular disease and spinal cord injury etiology is important in understanding the framework and context in examining the multi-facets of remote ventilated patient management.

Many patients suffering from the trauma of a spinal cord injury or neuromuscular disease must rely partially or even totally upon mechanical ventilation for respiration and holding on to life. In 2014, there were approximately 276,000 people with spinal cord injuries or spinal cord injuries (tetraplegia and paraplegia) in the United States and approximately 14%, or 38,000, of these were complete (Spinal Stats, 2015). In addition to these trauma statistics, there are over 30 types of muscular dystrophy diseases that can also lead to severe paralysis (Deenen et al., 2015). Although the number afflicted with neuromuscular diseases is hard to calculate, the cost of caring for only three of these diseases (amyotrophic lateral sclerosis or ALS, Duchenne muscular dystrophy or DMD, and myotonic dystrophy or DM) amounts $2.26B (Larkindale et al., 2014). Often, these patients are totally dependent upon mechanical ventilation for breathing, inhaling oxygen, exhaling carbon dioxide, and keeping cells, tissues, and organs alive—within minutes of oxygen deprivation, the body can develop shock which can cascade into death (Smith et al., 2014). When possible, ventilated patients are cared for in their homes, rather in the hospital setting by nurses, family, or paid caregivers. Care for ventilation patients remotely by telephone is more complex than face-to-face in the clinic exams for determining (a) when the patients will recover on their own, (b) should come to the clinic when convenient, or (c) when they should immediately go to the nearest emergency department (Smith et al., 2014).

Respiration is essential for maintaining human life. Inhaled air with a slightly higher concentration of oxygen is absorbed by the blood and transported to cells, tissues, and organs to support metabolism. A waste product, carbon dioxide is produced, absorbed by the blood, and transported to the lungs where the CO_2 is removed from the lungs during exhalation. These slight concentration differences in O_2 and CO_2 maintain the flow of oxygen into the bloodstream while simultaneously carbon dioxide is removed and expelled during exhalation. Without this continuous supply of oxygen to cells, tissues, and organs, the person ultimately dies. The lungs provide a structure to support this gas exchange through approximately 300,000,000 alveoli and 140 square meters of tissue surface, which comprise the pulmonary parenchyma (West, 2012). During inhalation, muscles in the diaphragm and chest wall expand and increase the volume of the lungs, which creates an internal lower pressure causes an inrush of external air to equalize the pressure. After full inflation and O_2 and CO_2 exchange, the thoracic muscles relax which increases air pressure in the lungs and results in exhalation. The total relaxed volume of the lungs is about 40% of the full inspiration volume. This cycle is repeated by contractions of the abdominal and chest wall muscles (Respiration, 2015). When the respiration cycle is inhibited by either disease or injury, the person is at risk of (cell, tissue, and organ) damage or death.

There are multiple types and severity levels of neuromuscular diseases and injuries that can prevent spontaneous and unassisted breathing. Neuromuscular dysfunction can be caused by diseases that impact the neural control or mechanics of respiration resulting in morbidity or mortality. An example of a lower motor neuron disorder (located in the central gray matter of the anterior horn of the spinal cord) is amyotrophic lateral sclerosis (ALS or Lou Gehrig's disease) with a median post diagnosis survival of 3 years. Although ALS ultimately leads to death, life can be prolonged with non-invasive ventilation or, in later stages, with a tracheostomy and invasive mechanical ventilation. Other lower motor neuron diseases include spinal muscular atrophy (SMA), poliomyelitis, and Kennedy syndrome to name a few. Peripheral neuropathies include Guillain-Barre (GBS) syndrome (whose only treatment is mechanical ventilation and supportive care), chronic inflammatory demyelinating polyneuropathy (CIDP), and Charcot-Marie-Tooth disease (CMT). Neuromuscular transmission disorders are typified by Lambert-Eaton syndrome, myasthenia gravis, and botulism (Gilchrist, 2002). Pulmonary dysfunction can also be caused by muscle diseases such as muscular dystrophy, hereditary channel disorders, polymyositis dermatomyositis, mitochondrial encephalomyopathies, congenital myopathy, and acid maltase deficiency. In summary, neuromuscular diseases can impact respiratory muscles, the spinal cord, motor and peripheral neurons, neural transmission, and polyneuropathies (which encompass axonal, demyelinating, hereditary, and acquired neuropathies; Gilchrist, 2002). In addition to neuropathies, genetics, drugs (isoniazid, vincristine), toxins (heavy metals), auto immune diseases, snake, scorpion, or spider bites, and a variety of other conditions can impact the diaphragm, abdominal, upper airway, or chest wall muscles lead to respiratory failure (MacDuff & Grant, 2003).

As mentioned, spinal cord injuries can result in respiratory failure. There are approximately 28 to 50 spinal cord injuries per million people in the U.S. as a result of vehicle, industrial, or athletic accidents. The higher the spinal cord injury, the greater the likelihood of respiratory dysfunction. Partial or complete diaphragmatic paralysis can result if the phrenic nerves are damaged by injuries above the C3 to C5 region. Spinal cord injuries in the C1 to C3 region result in quadriplegia (also called tetraplegia) and an inability to inhale and exhale adequately due to muscle dysfunction. Those with injuries in the C4 to C6 region may be able to contract their diaphragm muscles but may have weak intercostal muscles making it difficult to cough (clear secretions) and have variable oxygenation when supine versus sitting. Long-term mechanical ventilation is usually required with spinal cord injuries in the C1 to C3 region while those with C4 to C6 injuries may not unless there is pneumonia, pulmonary edema, or chest trauma (Perrin et al., 2004).

Those with complete spinal cord injuries above C4 are totally dependent upon mechanical ventilation to survive (Jones et al., 2015). Based upon the numbers given earlier, that is roughly translates to 33,000 to 47,000 ventilated patients on mechanical ventilation for life in 2014. This does not include neuromuscular disease patients who add to that number. In addition to the complexity of their care, the lifetime costs required to care for various degrees of spinal cord injury are listed in Table 1 (DeVivo, Chen, Mennemeyer, & Deutsch, 2011). It should be noted that dollars are converted from 2008 to 2014 values in the article "Spinal Cord Injury (SCI) Facts and Figures at a Glance" (Spinal Stats, 2015), which references DeVivo et al. (2011).

There are a multitude of neuromuscular disorders that vary depending upon the underlying cause, age of onset, severity, symptoms, and stage of progression. The Muscular Dystrophy Association (MDA) provides a great resource for learning about neuromuscular diseases. It lists 87 different diseases with links to detailed information regarding symptoms, causes, progression and more. Details from this MDA website have been compiled into Table 1, which categorizes the diseases (e.g., diseases of the neuromuscular junction or peripheral nerve, inflammatory myopathies) and lists disease types, age of onset, symptoms, causes, progress rate, and ventilator usage (MDA, 2016). Another excellent example which demonstrates the breadth of types of neuromuscular diseases is the “Comprehensive List of Neuromuscular Disorders Covered” by Muscular Dystrophy Canada, which lists 162 different types of neuromuscular diseases—they “vary according to characteristics such as pattern of inheritance, origin of the genetic mutation, incidence, symptoms, age of onset, rate of progression, and prognosis” (MDC, 2016, p. 1).

An overview of neuromuscular diseases can be developed from an examination of Table 1, which is populated with information from the MDA website (MDA, 2016). Neuromuscular diseases can be grouped by the underlying disease mechanism into categories such as diseases of the neuromuscular junction, diseases of the peripheral nerve, inflammatory myopathies, metabolic muscle diseases, motor neuron diseases, muscular dystrophies, myopathies due to endocrine abnormalities, and a general *other* category. Each of these categories contains a variety of more specific disease types such as Lambert-Eaton syndrome, Duchenne muscular dystrophy, or central core disease as examples. Often, a disease type is further decomposed into more specific types depending upon onset or other characteristics as exemplified by spinal muscular atrophy Type 1 (Werdnig-Hoffman), Type 2, Type 3 (Kugelberg-Welander), or Type 4. In the muscular dystrophy group, there are approximately 30 different types of myopathies (MDA, 2016).

The age of onset of neuromuscular diseases impacts the severity of the diseases. Congenital neuromuscular diseases impact the patient from birth on and tend to be the most severe, often leading to mortality. When diseases are acquired or developed later in life, the body has often had the opportunity to soften the impact by previously developing some essential enzymes, proteins, or structures (e.g., muscle, bone). Most of the neuromuscular diseases have a particular developmental age group when they predominantly manifest. Duchenne muscular dystrophy mainly becomes active in the 2–6 ages group. Amyotropic lateral sclerosis (ALS) develops on average in the late 50s but can also appear in childhood or young adulthood, too. Some genetic-based neuromuscular diseases can impact males more than females when the X chromosome is involved. The primary impact of disease onset can be summarized—the later in life it develops, the lower the impact while the opposite is true when neuromuscular diseases are congenital or in infants, which are the most vulnerable patient population (MDA, 2016).

Table 1

Onset, Symptoms, Causes, and Progress Rate of Neuromuscular Diseases (MDA, 2016)

Neuromuscular Disease Type	Age of Onset	Muscle Symptoms	Causes	Progress Rate
Diseases of Neuromuscular Junction				
Botulism	Any			
Congenital myasthenic syndromes	Infancy–Childhood	Weak, Fatigue, Droopy Eyes	Inherited, Autoimmune	Mild if get later
Lambert-Eaton (myasthenic) syndrome	Middle Age (Childhood)	Weak, eyes/legs/throat/face	Autoimmune, Comorbid Cancer	Treatable
Myasthenia gravis	W-28, M-42 average	Eyes, face, neck, limbs	Autoimmune (Bacteria/Viruses)	Slow
Diseases of Peripheral Nerve				
Charcot-Marie-Tooth disease	Childhood–Young Adulthood	Feet/legs/hands/ forearms, contractures, scoliosis	Genetic(~80)/protein deficiency	Slow, not life threatening
Dejerine-Sottas disease	Infancy			
Friedreich's ataxia	7–13 yrs.	Heart, Cerebellum, ataxia	Genetic,frataxin deficiency	Variable
Inflammatory Myopathies				
Dermatomyositis	Childhood–60 yrs.	Thighs, shoulders, neck, arms	Inflammation; Immune sys.	Discomfort
Inclusion-body myositis	> 50	Forearm/thigh/calf weakness	Unclear: Immune sys attacks	Slow; no life threat
Polymyositis	Childhood–60 yrs.	Upper arms/legs, neck	Autoimmune; not genetic	Little life threat

Table 1 (continued)

Neuromuscular Disease Type	Age of Onset	Muscle Symptoms	Causes	Progress Rate
Metabolic Diseases of Muscle				
Acid maltase deficiency (Pompe disease)	Infancy–Adulthood	muscles/heart/liver/ kidneys; cramps, pain	Prevents glycogen breakdown - no fuel to mitochondria	In infancy can progress to fatal; some forms fatal
Carnitine deficiency	Early Childhood			
Carnitine palmityl transferase deficiency	Childhood most severe (Adolescent/ Adult Too)			
Debrancher enzyme deficiency (Cori/Forbes disease)	1 yr.	liver swell; sometimes seizures	debracher enzyme gene	
Lactate dehydrogenase deficiency	Childhood, Adolescence, or Adulthood	exercise intolerance; rash	lactate dehydrogenase enzyme	
Mitochondrial myopathy (many types)	Early Childhood–Adulthood	weak; neurosensory damage	genetic defects	Varies with types
Myoadenylate deaminase deficiency	Infancy most severe (less later)	cramps, pain	ATP metabolism	Adult no progress
Phosphofructokinase deficiency (Tarui disease)	Childhood, Adolescence, or Adulthood	weakness, pain, cramps	Gene defect in: phospho-fructokinase/-rylase/ glycerate kinase or mutase enzyme	not progressive
Phosphoglycerate kinase deficiency		anemia, spleen, mental retardation		Earlier is worse
Phosphoglycerate mutase deficiency		rust urine, cramps, pain		Usually slow
Phosphorylase deficiency (McArdle disease)		cramps, pain, exercise intolerance		Slow/no progress
Motor Neuron Diseases				
Adult spinal muscular atrophy (Type 4)	Infancy on	Upper arms/back/legs	Gene defect chromosome 5	infancy more severe
Amyotrophic lateral sclerosis (ALS)	Late 50s average, (Childhood, Young Adulthood too) M>W.	weak, soft, spastic, stiff, tight	Unknown; genetic predisposition	varies 3–20+ yrs.
Infantile progressive SMA (Type 1, Werdnig-Hoffmann disease)	Birth–6 mos.	weakness voluntary muscles—shoulders, hips, thighs, back; breathing, swallowing, difficulty—mild to severe	Survival of Motor Neuron (SMN) on Chromosome 5 protein deficiency; types 1–4	Most severe if onset is in infancy
Intermed. SMA (Type 2)	6 mos.–3 yrs.			
Juvenile SMA (Type 3, Kugelberg-Welander disease)	1–15 yrs.			
Spinal-bulbar muscular atrophy (Kennedy disease)	15–60 yrs.	facial/swallowing; limb weakness	X chromosome defect	slowly over decades

Table 1 (continued)

<table>
<tr><th>Neuromuscular Disease Type</th><th>Age of Onset</th><th>Muscle Symptoms</th><th>Causes</th><th>Progress Rate</th></tr>
<tr><td colspan="5">Muscular Dystrophies</td></tr>
<tr><td>Becker muscular dystrophy</td><td>2–16 yrs.</td><td>heart, pelvis, hips, thighs, heart</td><td>dystrophin/ chromosome X</td><td>survive: mid/late adulthood</td></tr>
<tr><td>Congenital muscular dystrophy</td><td>At or Near Birth</td><td>Issues w: spine, respiration, learning, eyes, seizures</td><td>mutation > protein needed for muscles, eyes, brain</td><td>varies with type</td></tr>
<tr><td>Distal muscular dystrophy</td><td>Childhood–Adulthood</td><td>wasting in hands, forearms. Lower legs</td><td>inherited, 8 genes, protein</td><td>slowly progressive</td></tr>
<tr><td>Duchenne muscular dystrophy</td><td>2–6 yrs.</td><td>progressively affects: arms, heart, resp. muscles</td><td>X chromosome defect</td><td>survive to: 30s–50s</td></tr>
<tr><td>Emery-Dreifuss muscular dystrophy</td><td>Childhood–Early Teens</td><td>stiff joints, conduction block, wasting/weak</td><td>defect; nucleus membrane protein</td><td>Progresses slowly</td></tr>
<tr><td>Facioscapulohumeral muscular dystrophy</td><td>Childhood–Early Adulthood</td><td>face/shoulder blades/ arms</td><td>inherited; chromosome 4</td><td>most normal life span</td></tr>
<tr><td>Limb-girdle muscular dystrophy</td><td>Childhood–Middle Age</td><td>pelvic/shoulder girdle</td><td>15 different gene defects</td><td>varies w/defects</td></tr>
<tr><td>Myotonic dystrophy (Steinert disease)</td><td>Birth–Early Childhood</td><td>can't relax muscles voluntarily</td><td>chromosome 3 or 19 defect</td><td>slowly; childhood worse</td></tr>
<tr><td>Oculopharyngeal muscular dystrophy</td><td>40s or 50s</td><td>difficulty swallowing/eyes open</td><td>inherited; clumps in muscles</td><td>Slow</td></tr>
<tr><td colspan="5">Myopathies Due to Endocrine Abnormalities</td></tr>
<tr><td>Hyperthyroid myopathy</td><td>Childhood–Adulthood</td><td rowspan="2">weakness/stiffness; skeletal deformities; difficult swallowing/ breathing</td><td rowspan="2">inherited or thyroid (endocrine)</td><td rowspan="2">usually non-progressive</td></tr>
<tr><td>Hypothyroid myopathy</td><td>Infancy - Childhood</td></tr>
<tr><td colspan="5">Other Myopathies</td></tr>
<tr><td>Central core disease</td><td>Birth–Infancy</td><td rowspan="5">weakness/stiffness in voluntary muscles; atrophy; skeletal deformity</td><td rowspan="5">genetic mutations > protein defects; inherited or thyroid (endocrine)</td><td rowspan="5">Non-progressive</td></tr>
<tr><td>Myotonia congenita</td><td>Infancy–Childhood</td></tr>
<tr><td>Myotubular or Nemaline myopathy</td><td>Birth–Infancy</td></tr>
<tr><td>Paramyotonia congenita</td><td>Childhood–Early Adulthood</td></tr>
<tr><td>Periodic paralysis (Inherited/Endocrine)</td><td>Any Age</td></tr>
</table>

Note: SMA = Spinal Muscular Atrophy

Symptoms vary across all neuromuscular diseases quite a bit. Some neuromuscular disease disorders are differentiated by the organs (e.g., eye, brain, heart, liver, spinal cord, kidney, or spine) or muscle groups (e.g., face, throat, hands, limb girdle, hands, thighs, or forearms) they impact. Symptoms also include weakness, ataxia, dyspnea, fatigue, rust colored urine (muscle wasting), seizures, pain cramps, exercise intolerance, stiffness, spastic, swallowing/speech/chewing/breathing difficulties, and many more symptom variations. In many cases, symptoms can flare up and then abate, progress to a fixed state, or sometimes totally disappear (MDA, 2016).

Causes of neuromuscular diseases are also quite diverse. Inherited or acquired genetic mutations are a cause of neuromuscular diseases, often on very different chromosomes (3, 4, 5, 19, X…) or involving a combination of genes such as distal muscular dystrophy which can involve up to 8 genes, or 15 genes in limb-girdle muscular dystrophy. The impact of genetic mutations can also lead to different disease mechanisms. Some result in autoimmune diseases where the body's immune system attacks the patient's body systems rather than some invading pathogen. Some neuromuscular diseases can be comorbid with other diseases such as cancer (Lambert-Eaton myasthenic syndrome). Other mutations impact protein folding, enzyme production, metabolism, endocrine function, glycogen breakdown or ATP metabolism, and structural impact such as muscle wasting, myelin nerve sheath degradation, or even substance clumping in muscles. Some diseases can also simply be acquired such as Botulism, a deadly nerve toxin created from a bacterial infection, which can result in paralysis and death. In some cases, the cause is unknown, but some suspects are bacteria, viruses, or some environmental agent that triggers the disease (MDA, 2016).

An understanding of the progression of neuromuscular diseases from onset to the state of invasive mechanical ventilation using a tracheostomy is essential for effective remote home ventilated patient management. The downward spiraling progression diagram in Figure 4, developed from the paper by Khatwa and Dy (2015), depicts some of the conditions, symptoms, treatments, and interventions as the patient migrates to a more complex level of care. The onset of a neuromuscular disease begins with non-life threatening symptoms such as stiff, sore, and weak muscles followed by ataxia, dyspnea, scoliosis, and body structural alteration. Worsening neuromuscular disease factors (weakness in diaphragm respiratory/upper airway/craniofacial muscles, impaired coughing, secretion difficulties, deformity) lead to a declining ventilator drive can lead to sleep apnea (Irfan, Selim, Rabinstein, & Louis, 2015). Sleep apnea becomes progressively worse over time, initially occurring only during REM (rapid eye movement) sleep (Stage 1), then developing during REM and non-REM sleep (Stage 2), and finally progressing to continuous diurnal hypoventilation (Stage 3; Khatwa & Dy, 2015).

Some neuromuscular diseases have a slow progression while others have a rapid spiral downward with worsening symptoms combated by specialized treatments and interventions to slow the impact of the disease. In the most severe cases, progression finally leads to respiratory failure and the need for invasive mechanical ventilation via a tracheostomy. The combination of infections, deformity, muscle weakness, organ damage, and high maintenance treatments take an extreme psychological, financial, and emotional toll on the patient, caregivers, and family (Khatwa & Dy, 2015).

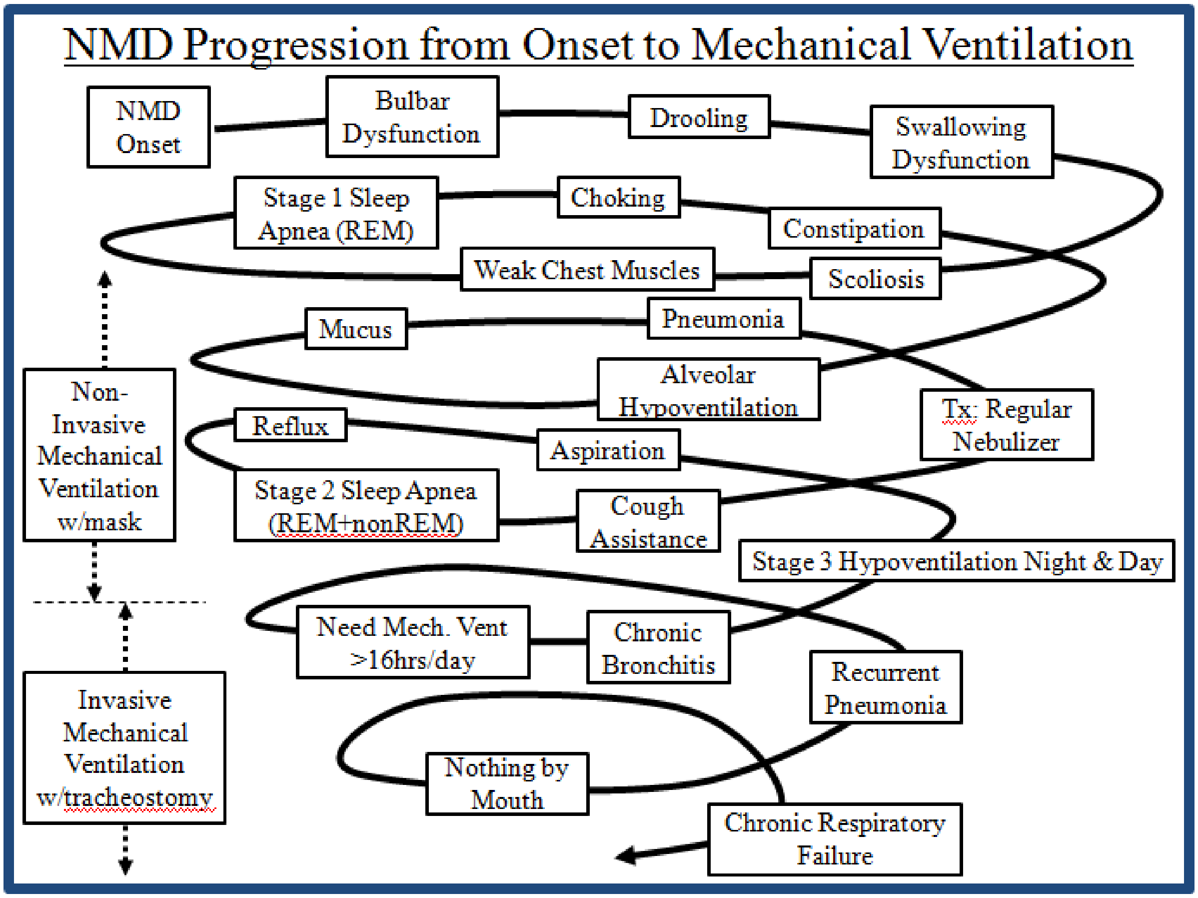


Figure 4. The downward spiral of neuromuscular disease progression from onset to invasive mechanical ventilation (tracheostomy).

Regarding life expectancy in spinal cord injuries (Table 2), there were approximately 276,000 spinal cord injury patients in the U.S. in 2014, and of these 14%, or about 38,000 patients (in the range of 33,000 to 47,000), had spinal cord injuries at or above C4 and were 100% mechanical ventilator dependent (Jones et al., 2015).

Table 2

Life Expectancy Post-Injury If Patient Survives the First 24 Hours (or Survives at Least 1 Year; SCI Facts, 2015)

Life expectancy in years for post-injury by severity of injury and age at injury						
Age at Injury	**Life Expectancy With No Spinal Cord Injury**	**AIS D – Motor Functional at Any Level**	**With Paraplegia**	**Low Tetra (C5-C8)**	**High Tetra (C1-C4)**	**Ventilator Dependent Any Level**
20	59.3	52.6 (53.0)	45.0 (45.5)	39.9 (40.6)	35.6 (36.9)	19.2 (25.3)
40	40.4	34.2 (34.6)	27.6 (28.0)	23.3 (23.9)	19.9 (20.9)	8.7 (12.4)
60	23.0	18.0 (18.2)	13.0 (13.3)	10.1 (10.5)	8.0 (8.6)	2.1 (3.9)

Note: For persons who survive the first 24 hours (survive at least 1 year) post injury

Cost of Remote Ventilated Patient Management

From an expense of care point of view, the cost of caring for only three types of neuromuscular diseases, amyotrophic lateral sclerosis (ALS), Duchenne muscular dystrophy (DMD), and myotonic dystrophy (DM), amounts to around $2.26B for cost of care annually for these three diseases alone (Larkindale et al., 2014). The costs for caring for patients with spinal cord injuries for the first year, subsequent years, and lifetime costs are listed in Table 3 (Spinal Stats, 2015). The higher the injury on the cervical spine (e.g., between C1 and C4), the greater the cost of care. Note the table is based on original data from DeVivo et al. (2011) and converted to 2014 dollars in Table 3 by Spinal Stats (2015).

Table 3

Estimated Lifetime Costs for Patients with Spinal Cord Injuries (Spinal Stats, 2015)

Severity of Injury or neuromuscular disease	Average Yearly Expenses (in 2014 dollars)		Estimated Lifetime Costs by Age At Injury (discounted at 2%)	
	First Year	Each Subsequent Year	25 Years Old	50 Years Old
High Tetraplegia (C1–C4)	$1,064.716	$184.891	$4,724,181	$2,596,329
Low Tetraplegia (C5–C8)	$769,351	$113,423	$3,451,781	$2,123,154
Paraplegia	$518,904	$68,739	$2,310,104	$1,516,952
Incomplete Motor Functional at Any Level	$347,484	$42,206	$1,578,274	$1,113,990

Beyond the complexity of configuring the ventilator, additional factors that impact the caregiving process include psychological factors and caregiver burden. Caregivers may lack confidence or be fearful that that may make a mistake which adds to their burden. They may have inadequate training or have forgotten their training. Indecision about whether to take the ventilated patient to the emergency department, in the event of an illness, adds to the uncertainty the caregiver must manage (Pagnini et al., 2012).

Complexity of Mechanical Ventilators

Beyond the biological, psychological, emotional, financial, and medical complexities of managing neuromuscular diseases and spinal cord injuries discussed in the previous sections, it is important to grasp the added complexity of simply managing mechanical ventilators and the risk factors of remote/home mechanical ventilation.

Mechanical ventilators are complex electromechanical systems. There are many different types of ventilators (as shown in Figure 5 [e.g., Trilogy 100, LTV 950, Puritan Bennett 840, and many others]; Ventilators, 2016). Mechanical ventilators require training and a high level of expertise to interpret the data, breathing waveforms, and the patient's condition to properly adjust their settings.

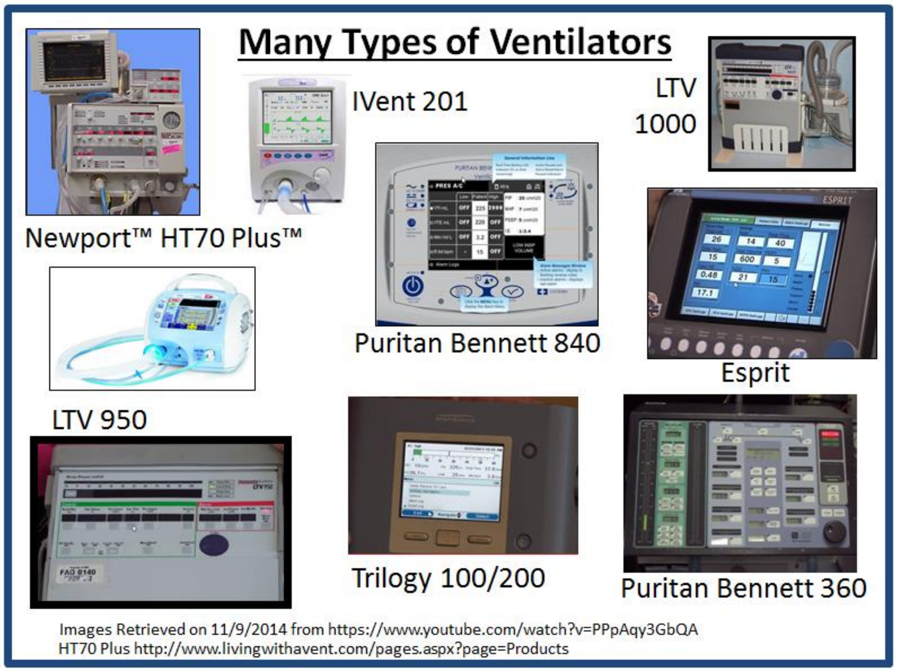


Figure 5. A comparison of the wide diversity in mechanical ventilators appearance, configuration, and control (Ventilators, 2016).

Although there are many different types of ventilators, the respiratory therapist (RT) must be familiar with the unique types of settings of each ventilator to configure them properly care for the patient's particular respiration requirements. Using one example, the Trilogy 100 as shown in Figure 5, there are 9 different modes and 36 different parameters that can be configured—this amounts to 216 different configuration combinations (Trilogy, 2014). In addition, there are level adjustments within configurations that also need to be set on the Trilogy 100 (Trilogy, 2014) to optimize the patient's respiration—too little ventilation leads to poor oxygenation and dyspnea, while too much can lead to lung and alveolar distention damage or death (Slutsky, 1993).

Even assembly and maintenance of ventilators can be challenging as seen in Figure 6 showing an exploded view of the ventilator. Tubes can become disconnected or plugged, and there can be a variety of other problems from battery problems to poorly connected tubes.

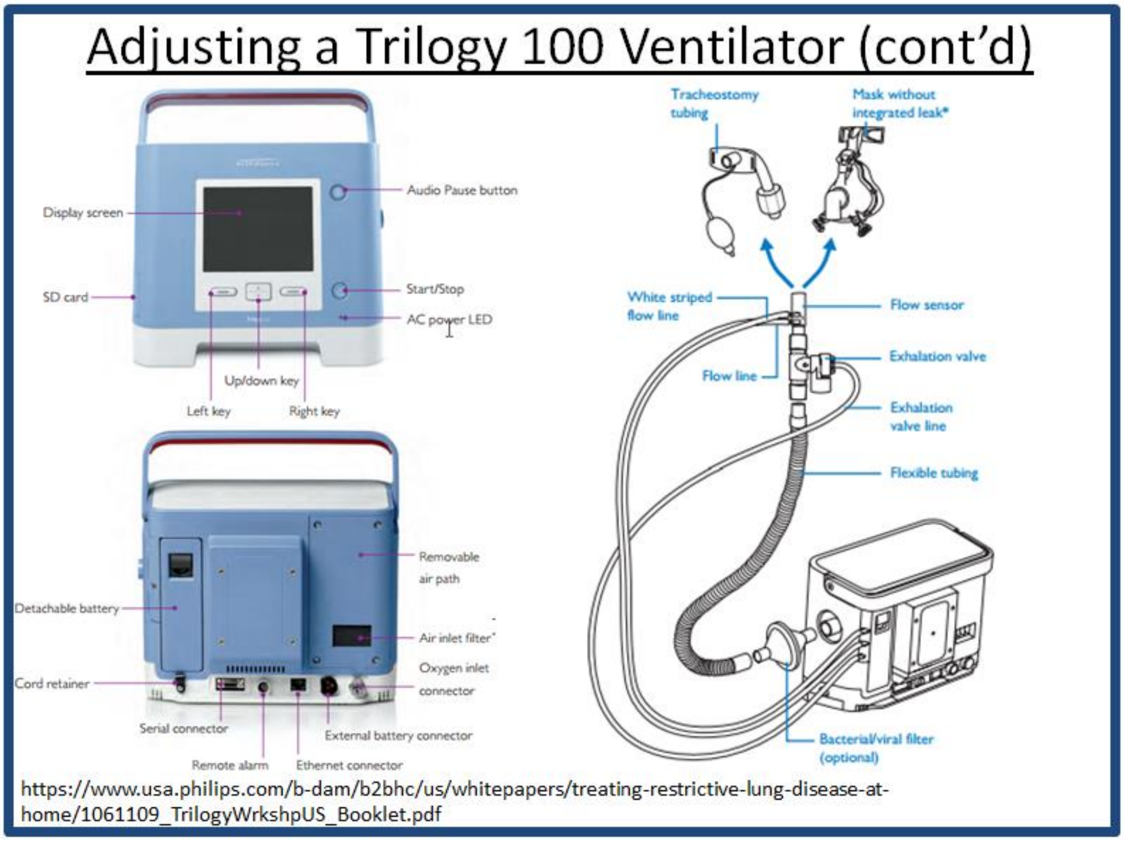


Figure 6. An exploded view of the Trilogy 100 ventilator.

Configuring a mechanical ventilator depends upon a combination of the patient's condition and respiratory functioning, the current configuration screen settings, analysis of stored ventilation data, and examination of the respiration waveforms to arrive at the new optimum parameter settings. Some of the Trilogy 100 screens settings and waveforms are shown in Figure 7 (Trilogy, 2014).

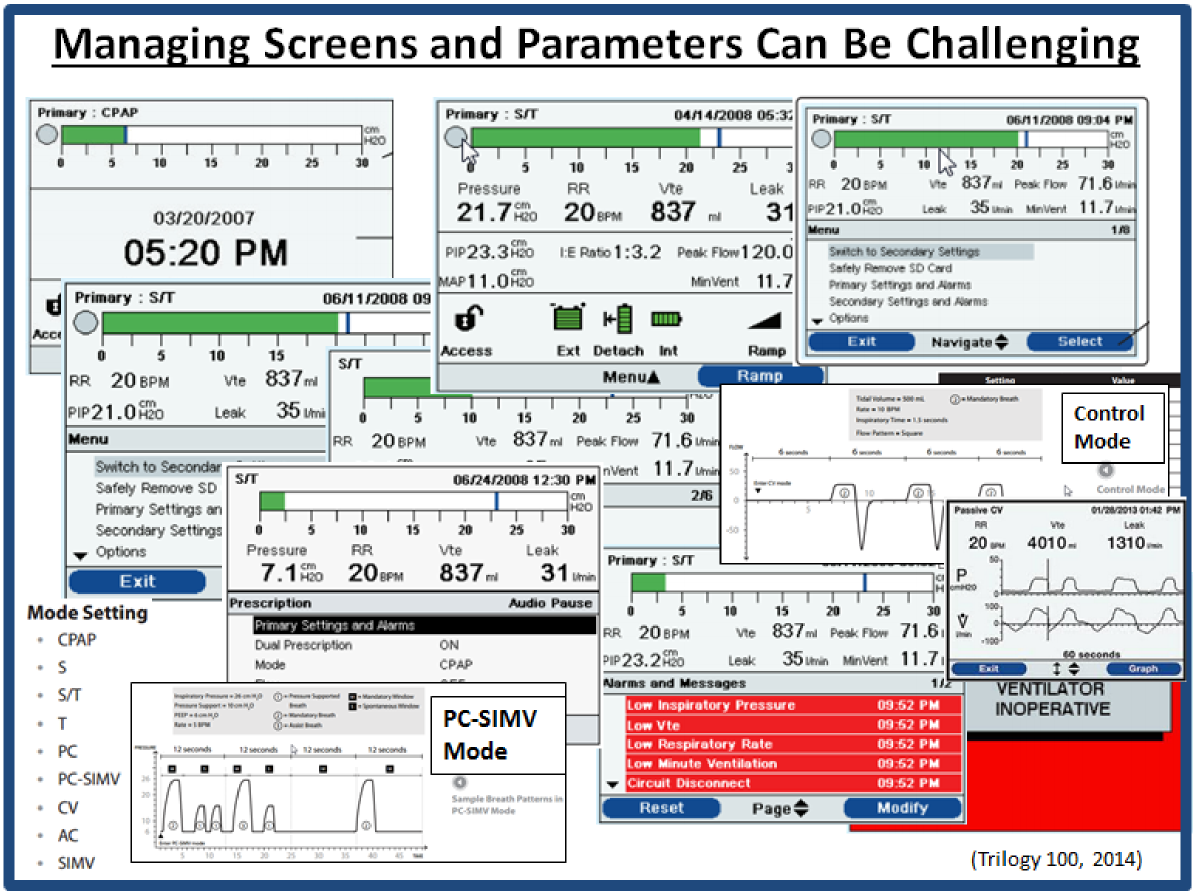


Figure 7. Complexity and variety of Trilogy 100 ventilator configuration settings and waveform screens (Trilogy, 2014)

Interpreting and integrating the mechanical ventilator configuration, operational screens, breathing waveforms, and the status condition of the ventilated patient is a complex task for the trained professionals as well and especially for new caregivers or family caring for the ventilated patient. Once the problems with the current configuration are determined, a new configuration must be programmed into the ventilator.

Determining new configuration settings can be challenging due to the large number of mode and parameter options as exemplified in Figure 8 for the Trilogy 100 (Trilogy, 2014) ventilator. Configuration options include a mix of nine or more different modes (e.g. CPAP, S/T, SIMV) and 36 variable parameters, which must be adjusted harmoniously to optimize the patient's breathing experience—too little ventilation leads to poor oxygenation and dyspnea, while too much can lead to lung damage or worse (Trilogy, 2014).

"Dialing In" a Trilogy 100 Can Be A Complex Task

Over 200 Setting Options

http://www.ahcah.com/Manuals/Trilogy%20100%20Patient%20Manual.pdf

9 Different Modes

36 Variable Parameters

Therapy Parameters	CPAP	S	S/T	T	PC	PC-SIMV	CV	AC	SIMV
Dual Prescription	√	√	√	√	√	√	√	√	√
Circuit Type	√	√	√	√	√	√	√	√	√
CPAP	√								
IPAP		√	√	√	√				
AVAPS (On, Off)*		√	√	√	√				
IPAP Max Pressure		√	√	√	√				
IPAP Min Pressure		√	√	√	√				
EPAP		√	√	√	√				
Inspiratory Pressure						√			
Pressure Support (PS)						√			√
PEEP						√	√	√	√
Tidal Volume		√	√	√	√		√	√	√
Breath Rate			√	√	√	√	√	√	√
Inspiratory Time			√	√	√	√	√	√	√
Trigger Type*		√	√		√	√		√	√
Flow Trigger Sensitivity	√	√	√		√	√		√	√
Flow Cycle Sensitivity	√	√	√			√			√
Ramp Length	√	√	√	√	√				
Ramp Start Pressure	√	√	√	√	√				
Flex *	√	√							
Rise Time		√	√	√	√	√			√
Flow Pattern							√	√	√
Sigh							√	√	√
Circuit Disconnect	√	√	√	√	√	√	√	√	√
Apnea	√	√	√		√	√		√	√
Apnea Rate		√	√		√	√		√	√
High Vte*	√	√	√	√	√	√	√	√	√
Low Vte*	√	√	√	√	√	√	√	√	√
High Vti*	√	√	√	√	√	√	√	√	√
Low Vti*	√	√	√	√	√	√	√	√	√
High Minute Ventilation	√	√	√	√	√	√	√	√	√
Low Minute Ventilation	√	√	√	√	√	√	√	√	√
High Respiratory Rate	√	√	√	√	√	√	√	√	√
Low Respiratory Rate	√	√	√	√	√	√	√	√	√
High Inspiratory Pressure							√	√	√
Low Inspiratory Pressure							√	√	√

* AVAPS, Trigger Type, Flex, High Vte and Low Vte settings are only available with the Passive circuit type. Trigger Type is not available with the Passive circuit in CPAP mode. High Vti and Low Vti settings are only available with the Active circuit with PAP.

Figure 8. Various modes and parameter settings used in configuring a mechanical ventilator (Trilogy, 2014).

A variety of problems can develop with mechanical ventilators. Without considering ventilator problems, mechanical ventilators are complex devices which require a high level of expertise to properly adjust their settings. There are multiple risk factors associated with the use of ventilators described by Reiter et al. (2011).

The Adult Assisted Ventilation Clinic—Clinical Quality Improvement

This research project focusing on remote home ventilated patient management originated from a collaborative clinical quality improvement project between the Assisted

Ventilation Clinic in the Michigan Medicine (Pulmonary and Critical Care Division of the Internal Medicine Department) and the eHealth Center (now called the Virtual Health Program). The Assisted Ventilation Clinic is jointly staffed by the Pulmonary and Critical Care Division and also the Physical Medicine and Rehabilitation Department—a single comprehensive staff that includes a nurse practitioner, a pulmonary and critical care medicine MD, a physical medicine and rehabilitation MD, a respiratory therapist, a dietitian, and a social worker, all in one location. Depending on the underlying condition a neurologist and cardiologist may also see the patient. A primary purpose of the clinic is to support patients who are being ventilated at home, either non-invasively using a mask that covers the facial orifices or invasively with the ventilator attached to a tracheostomy tube. Assisted Ventilation Clinic patients must agree to visit the clinic at least annually. However, in special cases, Assisted Ventilation Clinic staff does visit the patient's home for medication management, education, or patient assessment (AVC1, 2016). Currently, there are approximately 670 mechanically-ventilated patients supported by the Assisted Ventilation Clinic. This number is comprised of patients with spinal cord injuries and neuromuscular diseases at various stages of progression. Each of these patients was required to satisfy eligibility requirements to partner with the Assisted Ventilation Clinic, such as having at least two caregivers that are trained in caring for the complexities of home ventilated patient management (AVC2, 2016).

When possible, ventilated patients are cared for in their homes by nurses, family, or paid caregivers, rather in the hospital setting which is more expensive. In 2012 dollars, long-term ventilation care in the home costs $7,050 per month per patient while care in a hospital costs $21,570 per month per patient, a difference of $14,520 or a savings of $174,240 annually per patient (King, 2012). King also points out that the home environment is a much less intimidating than the ICU in terms of noise, light, overcrowding, limited visitation, sterile, view, and personally customizability. In Europe, the number of home ventilated patients averages 6.6/100,000 people, which if applied to the U.S. would mean there are approximately 20,000 people on home ventilation (King, 2012).

During home mechanical ventilation, things can and do go wrong with ventilators. Evidence in many research papers points to the value and effectiveness of using telemedicine in managing patients in the ICU by a remote intensivist physicians. Although some research had mixed results of telemedicine use in the ICU, a 2012 meta-analysis/systematic review found that overall for critically ill patients, telemedicine in the ICU reduced length of stay and mortality rates (Wilcox & Adhikari, 2012). Another multi-center study examining 56 ICUs, with a sample size of over 118,000 patients, observed many benefits of telemedicine in the ICU with reduced length of stay, lower mortality, and quicker alarm response due to earlier intensivist involvement (Lilly et al., 2014). However, moving the mechanical ventilation management from the ICU into the home environment also shifts burden of intensive care to the caregivers in the patient's home environment. Life threatening mechanical ventilation issues can develop for a variety of reasons. Some of those reasons include (a) malfunction where ventilator fails to alarm and alert caregivers of a mucus plug, tracheostomy tube dislodgement, patient being cyanotic, disconnections, or simply a delayed or no alarm at all; or (b) medical reasons—bowel obstruction, peritonitis, seizures, metabolic reasons, fall/accident, severe viral illness, tracheal bleeding/obstruction/accident, brain death, acute respiratory failure, cardiac arrest, infections/sepsis/multiple, or organ failure (King, 2012).

Migrating mechanically-ventilated patient management from the ICU to the home results in a totally new environment. The ICU is equipped with high-tech equipment, multiple LCD monitors, crash carts, cameras with pan, tilt, and zoom, and experienced support staff to assist the remote intensivist. In contrast, the home environment only has a telephone, a ventilator, a cough assist device, a caregiver—two very different environments. Although telephone-only remote ventilated patient management has been implemented broadly for many years, there are limitations. The next section discusses the limitations of telephone-only support and the potential advantages of using smart mobile devices such as Apple and Android smartphones and tablets.

Limitations of Telephone-Only Support vs. Benefits of Using Mobile Devices

A theoretical model is useful for describing the limitations of telephone-only support compared with using videoconferencing on mobile devices. The theoretical models of telephone-only support versus the model for videoconferencing are shown in Figure 9. In the telephone-only theoretical model, communications are limited to audio-only channels. In those channels, there is delay and uncertainty in both directions of communication between the patient/caregiver/family and the remote clinician. From the patient to the clinician, both delay and uncertainty are injected. The insertion of delay is apparent by referring back to Figure 7, the Trilogy 100 screens and waveforms, and the challenge faced by the caregiver trying to describe these images to the remote clinician using words only. There are two types of uncertainty injected as well. There is uncertainty in what is being described by the speaker as well as what is being perceived by the hearer. There is also delay and uncertainty injected in communication from the clinician to the patient/caregiver/family. Initially, there can be fundamental uncertainty such as which type of ventilator is being used and which screen is being described to the clinician. Delay is inherent in trying to paint a picture with words. Uncertainty is embedded in the communication by the clinician being unsure the state of the ventilator and unsure if the caregiver/family member is correctly following their guidance. Describing a ventilator screen or waveforms is time consuming and feedback is slow and cumbersome (Smith et al., 2014).

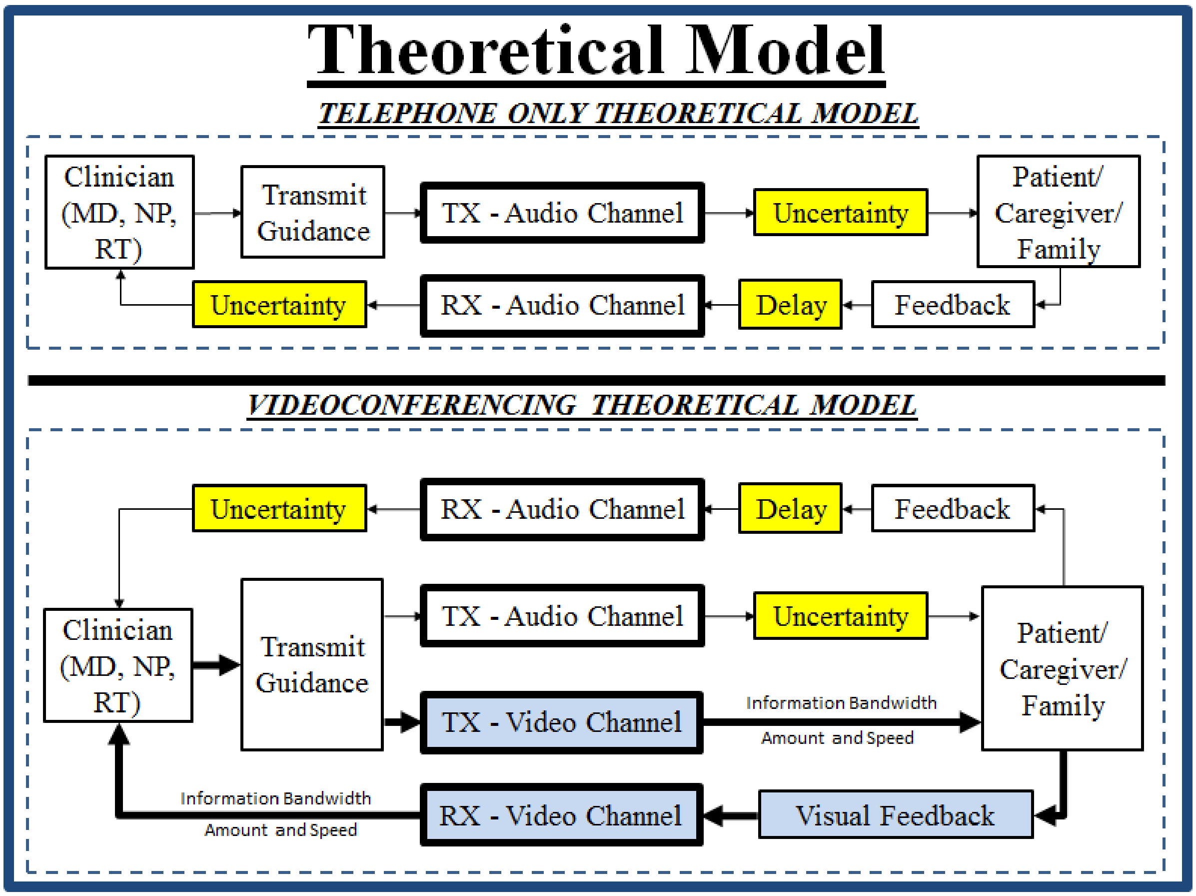


Figure 9. Theoretical models of telephone-only vs. videoconferencing.

In the videoconferencing theoretical model, there are two additional virtually instantaneous communication channels that provide video information in addition to the two audio channels. The volume and speed of information transferred between clinician and patient/caregiver/family is much greater than audio only. Immediate feedback allows the clinician to see exactly which screen the patient/caregiver/family member is observing.

Transmitting clinician guidance more rapidly and reliability of executing at the remote end is instantaneously verified by observing the patient/caregiver/family actions. The error of pushing the wrong button on a ventilator can be corrected instantaneously using visual feedback and by the clinician simply stating, “no, not that button, push the one just to the right of it.”

At this point, the discussion shifts from a theoretical model of telephone-only support versus videoconferencing to a review of the literature on remote telephone support for mechanical ventilation and telemedicine.

Telephone support for neuromuscular disease and spinal cord injury patients at home has been common practice as mentioned in the literature by Vitacca et al. (2006, 2007a, 2007b, 2009, 2010, and 2012) and range in implementation from remote support modes for tele-assistance to weaning the patient from a mechanical ventilator. Remote home mechanically-ventilated patient management via telephone-only support has been in place for several years at the Michigan Medicine Assisted Ventilation Clinic. Many of the limitations of telephone-only remote support of remote home mechanically-ventilated patients are described by clinicians actually practicing telephone-only support in the Michigan Medicine Assisted Ventilation Clinic and are described in Smith et al. (2014). Issues include the following challenges: an inability to see the viscosity or color of mucus or sputum, difficulties in assessing the patients overall wellness through interaction and seeing their behavior, inability to verify that guidance given is being followed correctly (such as adjusting ventilator settings or adjusting a cough assist device), uncertainty about which ventilator configuration screen is being displayed, the shape or color of a wound, and general ambiguity between the caregiver’s description and the clinician’s perception. There is also a time lag using verbal description versus just pointing the mobile device camera at something and instantaneously knowing to what they are referring.

Videoconferencing overcomes many of these barriers and limitations of telephone-only support by providing a window into the patient's environment. However, to equip a patient population with mobile devices or computers is cost prohibitive. The University of Michigan Accountable Care Organization (ACO) includes 120,000 patients. To equip them with smartphones for a period of 2 years would cost $3,800 per patient times 120,000 (patients in the ACO) which equals $456M. Even providing smartphones for the approximately 670 patients in the Assisted Ventilation Clinic alone would cost $1.52M, and then the devices would be obsolete after a few years (PC World, 2015). A logical alternative is to utilize the mobile devices and computers owned by the patient population, caregivers, and family. The overriding question that needed to be answered was "what mobile devices or computers do patients, caregivers, and family have access that could be used in the care and support of the mechanically-ventilated patient?" A key component of this research was the intent to utilize patient owned smartphones and tablets rather than providing technology directly to the patients, caregivers and family.

Videoconferencing (also called video calling when only two people are connected) has been expensive to implement in the past. However, with the evolution and cost reduction of mobile devices, many people now own their own smartphone or tablet equipped with a high-resolution LCD and cameras—exactly what's required to support videoconferencing. It is cost prohibitive for a hospital system to equip each patient with a smartphone or tablet and telephony service to enable video conferencing between patients and clinicians. The mass production and sales of smartphones and tablets to the mass market has created an infrastructure that is regularly upgraded at no cost to the hospital system by patients. A recent UN study found that of the 7 billion people in the world, 6 billion have access to mobile phones while only 4.5 billion have access to working toilets (PhonesThrones, 2014). The alternative is to utilize patient and caregiver owned mobile devices (smartphones and tablets)—in essence, patients are purchasing, upgrading, and providing a usable infrastructure through which telemedicine can be practiced between mechanically-ventilated patients and clinicians. Utilizing this extended infrastructure based on patient or caregiver owned or accessible mobile devices makes videoconferencing financially and technologically possible between the patient and clinician. Leveraging this patient-owned technology has opened the door for remote ventilated patient management. Unlike telephone-only support, hospital administration is also interested in this type of intervention which allows billing insurance for these services.

Although telephone ownership is common, it was unknown how many and what types of mobile devices are owned or accessible to the Assisted Ventilation Clinic ventilated patients and their caregivers. Further, their level of mobile device expertise was also unknown, making it unclear if they could download a videoconferencing application and use it. Finally, it was unclear how receptive the ventilated patients and caregivers are to embracing telemedicine videoconferencing for remote ventilator management and actually using telemedicine. Finding answers to these questions set the stage for this descriptive study—the descriptive questionnaire method was used to query the University of Michigan mechanical ventilated patient population of approximately 670 patients. A slice in time (November 2016 to February 2017) sample of random patient visits to the clinic was chosen because it was representative of the 670 patient population and their caregivers. Results are helpful in planning remote ventilation research projects, developing policies for using mobile devices, understanding how prevalent mobile devices are among the ventilated patient population, and determining patients' and caregivers' *intent to use* this service.

Current State of Remote Ventilated Patient Management Research

The current state of research using mobile devices and videoconferencing for remote home mechanically-ventilated patients is included in this section. An understanding of the latest research in this area defines the most current boundary of research and how this descriptive study contributes to the body of research knowledge.

To continue the literature review, the first mention of what could be called videoconferencing in remote ventilated patient care was a study by Miyasaka et al. (1997) mentioned earlier in the Nature and Significance section. The evolution of technology has been critical to the advancement of telemedicine for remote care. Parameters that capture this evolution are terms like resolution, frame rate, bandwidth, ISDN, image sensors, 4G, LTE, WiFi, and ARM microprocessors. For videoconferencing to be an effective tool, adequate bandwidth, frame rate, resolution, and a reliable or predictable communication connection are essential. The Miyasaka et al. (1997) research occurred between 1994 (September) and 1996 (March), or 18 months. Initially they had evaluated an analog videophone (VisualPhone VP2000, Nissei-Sangyo of Tokyo Japan) for remote care. Although the resolution of it was 256 pixels X 240 pixels and was adequate for some medical procedures, the frame rate of one every 18 seconds was far from what could be called videoconferencing. By 1997, Japan had implemented an ISDN system nationally, which provided a guaranteed telephony connection rate of ISDN 64, or 64K bytes per second, and the network could guarantee a frame rate of 10 to 12 frames per second for a screen size of 320 pixels x 200 pixels. This technology opened new possibilities for what could be called videoconferencing. The goal of the Miyasaka et al. (1997) study was to connect respiratory specialists in the pediatric intensive care unit (PICU) to remote specialists who were in the pediatric patients' homes where they were receiving respiratory care. The researchers modified 15 videophone units for use in patients' homes and 10 were actually installed. The clinician/patient interactions and operations with the videophones were basically the same as with regular telephones—other than having a video link into the home. The cost of new technology in 1997 was a significant factor to consider in telemedicine implementations—during this study, the purchase price of the videophone was $6,000 while leasing cost $1,000 plus $150 a month. By 1996, the videophone price had dropped to $2,000 demonstrating rapid price change as new technologies mature (Miyasaka et al., 1997). Results of this study were positive with a significant increase in phone calls (from 11 before to 58 after installation) with $p < .004$; a reduction in unscheduled hospital visits from 24 before, down to 5 visits after (an 80% decrease with $p < .01$); a decrease in days of hospitalization from 22 days, down to 10 (not statistically significant); and a time savings of 51.2 hours by physicians and 95 hours by family and patients. The recommendations were that using videophones was practical and effective and warranted for use in remote care (keeping in mind that $n = 10$ for this study).

Efforts to move mechanical ventilation initiation from hospital to home are captured in a 2014 stratified block randomization study in the Netherlands. The study focused on 77 patients with neuromuscular disease, thoracic cage disorder, and chronic respiratory failure to compare home initiation of (non-invasive) mechanical ventilation versus hospital-initiated mechanical ventilation initiation. Special software was created, running on a laptop that collected data from a ventilator, a humidifier, and a transcutaneous monitor, and transmitted back to the hospital and NP each morning. The study results indicated moving initiation to the home environment was not inferior to the hospital setting, perfusion was as effective, quality of life was maintained, and a cost savings of €3,000 was realized (Hazenberg, Kerstjens, Prins, Vermeulen, & Wijkstra, 2014). This study focused on non-invasively mechanically-ventilated patients—if problems developed, they could discontinue treatment. However, invasively ventilated patients can have additional complications, especially in cases where mechanically ventilation is required 100% of the time.

A study published in 2014 was conducted in Spain by remotely monitoring three mechanically-ventilated patients with severe neuromuscular disease over a period of 5 years (2005 to 2010). The system technology included telemonitoring and videoconferencing. The telemonitoring variables included O2 saturation and blood pressure (visible on the monitor and control center), heart rate, and an electrocardiogram. Equipment included the videoconferencing communication system, a sphygmomanometer, an ECG system, a pulse oximeter, a mechanical ventilator, an alarm button, and a web interface for entering vitals. The videoconferencing system was based upon a television connected to a set top box, which was then connected to a residential gateway and out to the Internet through an ADSL modem to the control center. The patient could interact with the television/set top box system to enter biomedical data which was transmitted to the control center. A CSQ-8 Client Satisfaction Questionnaire indicated an acceptable level. Over the study period of 5 years, there were 269 oximetry measurements, 110 blood pressure measurements, and 290 videoconferencing sessions. Hospital admissions decreased from 18 down to 3 with the telemedicine interventions. Although this system didn't have the flexibility of mobile devices, its videoconferencing and telemonitoring capabilities demonstrated improvement in remotely caring for three mechanically-ventilated patients (two invasive and one non-invasive) patients with severe neuromuscular diseases (scapular humeral dystrophy, ALS, and Duchenne diseases) over a period of five years (Zamarrón et al., 2014). The Zamarrón study made no specific mention of time or cost savings beyond a reduction in hospital admissions but stated the system was effective for remote neuromuscular patient care.

Although not specifically focusing on neuromuscular disease or spinal cord injury patients, the use of mobile devices in caring for children at home was explored in a 2014 study in Sweden by Fredriksson, Groth, Rasanen, Bergius, and Rylander (2014). In particular, 15 Apple iPad II tablets equipped with VidyoMobile videoconferencing software were used by both caregivers in the home or patients themselves to communicate with specialists at a centralized hospital. Their name for the tablet plus software was MVCT (or mobile video-conferencing tool). Various communication technologies were used including cellular 4G communications, which were stable and reliable, while 3G was slow and unreliable. In some cases where cellular was unreliable, the caregivers using the tablet were able to use the patient's WiFi Internet connection for communications. Over the 18-month period of this observational qualitative study, 23 videoconferencing calls were made by a visiting nurse in the patient's home to the medical staff specialists at the central hospital location. Approximately 400 hours of structured and unstructured clinical interviews were observed between clinicians and patients. Benefits of using their MVCT iPad II included wound management, observing patient behavior, providing care at home and the MVCT's maneuverability. In addition, physicians used the videoconferencing to read nonverbal cues and the body language of patients and caregivers. However, shortcomings of the MVCT included nurses complaints that it was "yet another thing to bring along," and there were reservations about learning to use the new technology, especially in front of patients and caregivers in which a lack of expertise using the technology could translate into their medical authority and expertise being questioned by caregivers and patients. There were also technical glitches due to older unreliable wireless service. Also noted was the fact that rapid movement of the iPad/MVCT during videoconferencing had a disorienting effect. Recommendations were made for adequate training to remove anxiety and unfamiliarity with the MVCT and for the development of workflows and processes that integrate videoconferencing into clinical practice (Frediksson et al., 2014).

Based upon the current research literature, one study stands out being very similar to the Assisted Ventilation Clinic/Virtual Health approach to remote home mechanically-ventilated patient management using patient-owned technologies. A 9-month 2014 study by Casavant et al. (2014) took place at the Boston Children's Hospital (associated with the Harvard Medical School) focusing on pediatric patients diagnosed with neuromuscular diseases but primarily with spinal muscular atrophy, hereditary progressive muscular dystrophy, and static encephalopathy with cerebral palsy. Similar to the Michigan Medicine Assisted Ventilation Clinic, since 2007, they have had a Critical Care, Anesthesia, Perioperative Pain Extension (CAPE) and Home Ventilation program to care for approximately 670 patients. Both the Casavant et al. (2014) program and the Assisted Ventilation Clinic program have a respiratory therapist, a nurse practitioner, a social worker, and pediatric intensivist that collaborate to care for this unique patient population by regular patient visits to the clinic, visits to the patient's home when necessary, and remote telephone support. In the paper, Casavant et al. (2014) also points out the scarcity of research on remote home mechanical ventilation patient management, similar to this literature search and review.

Their motivation to implement videoconferencing revolved around (a) reducing the care burden, stress, and risk on the patient and caregivers in transporting the patient to the emergency department or clinic; (b) eliminating travel itself for clinicians, caregivers, and the patient; and (c) using videoconferencing so they can see the patient in real-time. Unlike our proposal of using mobile devices for videoconferencing, they selected patients with a computer, Internet access, and camera and then provided free Vidyo software for download to the patient's computer. Patients without access to a computer were excluded from the study (all the families did have access to computers, so it was a non-issue). The videoconferencing service was used in cases where visiting the patient at home was not possible. Fourteen families participated in the study and were given a CAPE-adapted questionnaire based on the Care Coordination Measurement Tool (CCMT) two to three months after the telemedicine teleconference. Overall results were positive. Based upon 27 videoconferencing encounters, 23 clinic visits, 3 emergency department visits, and most likely one hospital admission were avoided. Results from the CAPE modified CCMT survey indicated that 93% responded that the telemedicine service was easy or very easy to use, that 93% responded that the audio and video quality of the service were good or excellent, and 100% responded that it didn't raise monthly expenses. Significantly, patient families felt the clinician was better able to assess their child's condition such as ease of breathing by using videoconferencing. Of the 14 families, 11 felt videoconferencing provided better remote home mechanically-ventilated patient management while 3 felt that they were about the same (Casavant et al., 2014). Although the paper pointed out that laptops or hand-held devices could also be used (due to the Vidyo software platform flexibility), they did not specify versions of any mobile devices (e.g., iPhone 4S may not work but iPhone 5S may work). It was stated that the clinicians were able to see the patient's gastric tube, chest wall movement, tracheostomy, and ventilator settings, but it is unclear if mobile devices were used to provide close-up viewing.

The final literature review paper, by Bell et al. (2016), on the current state of research on remote mechanically-ventilated patient management is a comparison of remote respiratory therapists assessing and treating neonatal/pediatric patients in a remote PICU versus respiratory therapists face-to-face in the PICU assessing the same pediatric patient. Although our research focus is on assessing and managing remote patients in the home setting using mobile devices, valuable information is provided in this recent study.

After examining the literature, Bell et al. (2016) found no research on the participation of RT in the ICU using telemedicine and also no telemedicine research on remotely assessing neonatal/pediatric PICU patients that are being mechanically-ventilated. They state that using telemedicine is easy for an RT to observe and set ventilator parameters, and potentially, this ability might allow RTs to be more involved remotely in neonatal and pediatric ventilated patient care. The setting for the Bell et al. (2016) pilot study was the Massachusetts General Hospital in Boston where 16 RTs have been recruited to evaluate 11 patients in 40 assessments; 20 face-to-face assessments were performed by a randomly selected RTs, while 20 telemedicine assessments were done remotely by an randomly selected RTs on the same patients (or pairing one RT face-to-face, and one RT using telemedicine on the same patient simultaneously). During the RT face-to-face and RT telemedicine assessments, 14 parameters (some ventilator related, some patient respiratory related) on a form were filled out and compared for a single patient they were both evaluating—this would be two of the 40 total assessments. As mentioned previously, the value of equipment in the ICU environment is much higher than consumer-owned ICT. A Tandberg/Cisco cart (price = $35,000) was located in the PICU next to the patient and was connected through a Vidyo gateway to Vidyo client software running on a remote desktop/laptop system with a Logitech camera, which was being used by the remote telemedicine RT observed the patient in the PICU. The other randomly selected RT observed the patient face-to-face at the same time, and both were simultaneously completing the 14 variable patient evaluation form in an average of about 8 minutes (Bell et al., 2016). Of the 14 variables, (a) pressure control, (b) PEEP, (c) mean airway pressure, (d) breathing frequency, (e) FIO2, (f) I-E (inspiratory/expiratory) ratio, (g) Vt, (h) minute ventilation, and (i) O2 saturation all had significant correlation between the face-to-face RT and the telemedicine RT (all were $p < .001$ except the I-E ratio was $p = .040$), while (j) ventilation support increase and (k) presence of end title CO2 correlated 100%. Correlation was not significant for (l) presence of patient triggered breaths, (m) need for suctioning or increased ventilator support, and (n) breathing frequency higher. Additional variables the RTs would like to be added for evaluation were tele-stethoscope/auscultation, review of ventilator alarms, and the pressure of the endotracheal tube cuff (Bell et al., 2016). The Bell et al. (2016) study results showed that although mechanical ventilator configuration parameters can be easily viewed using telemedicine and 11 of 14 showed significant correlation between face-to-face and telemedicine settings, there were reservations about using telemedicine to evaluate patient-triggered dynamic parameters. Bell et al. (2016) also recommended integrating a telemedicine stethoscope and including additional assessment parameters in the evaluation such as ventilator synchrony, chest rise, pressure-volume loops, patient ventilator asynchrony, presence of auto-PEEP, and condensation in the ventilator tubes to determine if a remote RT using telemedicine can effectively assess those variables (Bell et al., 2016).

Remote Expert Collaborative Guidance

One of the goals of the Assisted Ventilation Clinic/Virtual Health project was to determine if remote caregivers at the patient's home could be guided by the RT and NP back in the clinic. To determine if this was possible, the Zero Ventilator Knowledge was created. An assistant administrator (admin), who had never seen, used, or been familiar in any way with ventilators, volunteered to be remotely guided by a RT and NP in a near-by clinical room to determine the extent he could be directed through various tasks. The activity captured by the term *Remote Expert Collaborative Guidance*.

This activity was conducted under the umbrella of improving the quality of patient clinical care and was reviewed with members of the institutional review board (IRB) to determine that approval was not needed to conduct these quality improvement exercises. However, IRB approval would be required if data collected was published at a future time—both Eastern Michigan University and University of Michigan IRB approval was required for this research project.

To begin the exercise, a clinical room with two different ventilators, Trilogy 100 (Trilogy, 2014) and a LTV 950, was set up, tubes were connected with a glove taped at the end to adjust pressure settings, and the admin was equipped with only his iPhone 5S and earbuds (previous tests indicated that when ventilator alarms sound, the noise volume drowns out audio communications with the remote clinicians). The admin was remotely guided through a variety of exercises to see how effective the interaction would be with no clinician present to guide the admin through a variety of tasks typical of those occurring during a clinical exam (see Figure 10 and Figure 11).

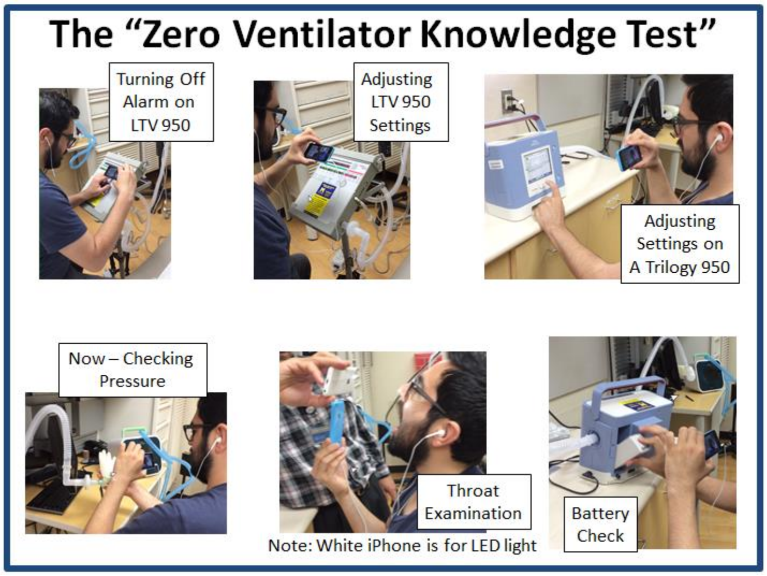


Figure 10. Zero Ventilator Knowledge test and expert collaborative guidance (1 of 2; Smith et al., 2014).

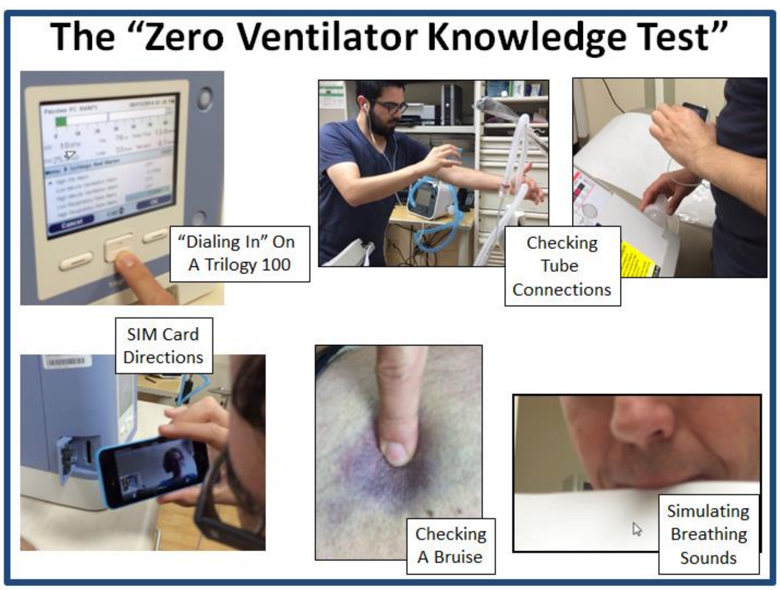


Figure 11. Zero Ventilator Knowledge test and expert collaborative guidance (2 of 2; Smith et al., 2014).

The remote RT and NP used an Apple iPad Air in a distant clinical room while the admin used a smartphone. The room was sabotaged with problems to simulate real world problems that patients and caregivers encounter—ventilators alarms were triggered, tubes were disconnected, and ventilator settings were incorrect. The administrator's smartphone was configured so he could see the remote NP/RT on his LCD during face-to-face videoconferencing. However, his smartphone being equipped with two cameras, his front camera could be pointed at him during face-to-face videoconferencing, or he could switch to the camera on the back of his phone (used for taking pictures) so the NP/RT could view the ventilator, see the numbers and buttons, and even see in real-time which buttons his finger was going to push to give immediate positive or negative feedback on his intended actions. A battery of tests was conducted while the admin was remotely guided by the NP/RT team as shown in Figures 10 and 11. Adjusting ventilator settings was the first exercise with the remote NP/RT easily reading the settings and screens, guiding the admin on changing screens or making adjustments, on two completely different ventilators, a Trilogy 100 and LTV 950, and demonstrating that as long as the NP/RT are familiar with the ventilator being used, the admin can be successfully guided through making adjustments. The admin was guided in making pressure adjustments to properly inflate a surgical glove, remove/reinstall the battery, checking tube connections, finding and following SIM card manipulation instructions, checking a bruise, and listening to breathing sounds remotely by breathing into several sheets of paper to simulate low-volume muffled or wheezing breathing sounds. One difficulty was discovered, the HipaaChat videoconferencing application had no ability to turn on the LED light (used for taking pictures) during the throat examination. We contacted the vendor requesting that they allow enabling the LED to avoid the need to also hold a separate light source and the camera to examine areas where light may be limited (such as examining wounds, bedsores, a tracheostomy, or the patient's throat).

The next step was to conduct this experiment with three actual mechanically-ventilated patients to determine if it was feasible for them to download the HipaaChat videoconferencing application and for a remote clinical exam to be conducted, including checking ventilator settings, adjusting a cough assist machine, examining trachestomies, and other clinical exam tasks. All three patients, using their mouth sticks, were able to download the application using their personally-owned mobile devices, successfully conduct a pre-test to make sure the videoconferencing connection was functional, and then begin clinical interaction between the NP/RT and the patient/caregiver at home as depicted in Figure 12. The patient-owned technology used in the remote testing included an Apple iPhone 4S, iPad Mini, an iPhone 5S, and an Android Smartphone. The patient tests also exposed issues that would need to be examined more closely in future qualitative and experimental research. Lighting was quite variable in the different patient home environments—fluorescent, incandescent, and natural lighting impacted videoconferencing quality as well as where the light source was positioned relative to the patient or equipment. Image quality was barely adequate using the iPhone 4S and iPad Mini and depended heavily upon the expertise of the NP/RT in diagnosing and assessing. Lighting also impacted color, another area requiring more analysis and research in the future. However, overall, the patients and caregivers quickly adapted and utilized using mobile devices to interact with the NP/RT, collaboratively change a cough assist device's settings, examine capillary nail bed refill, tracheostomies, and check and change ventilator settings.

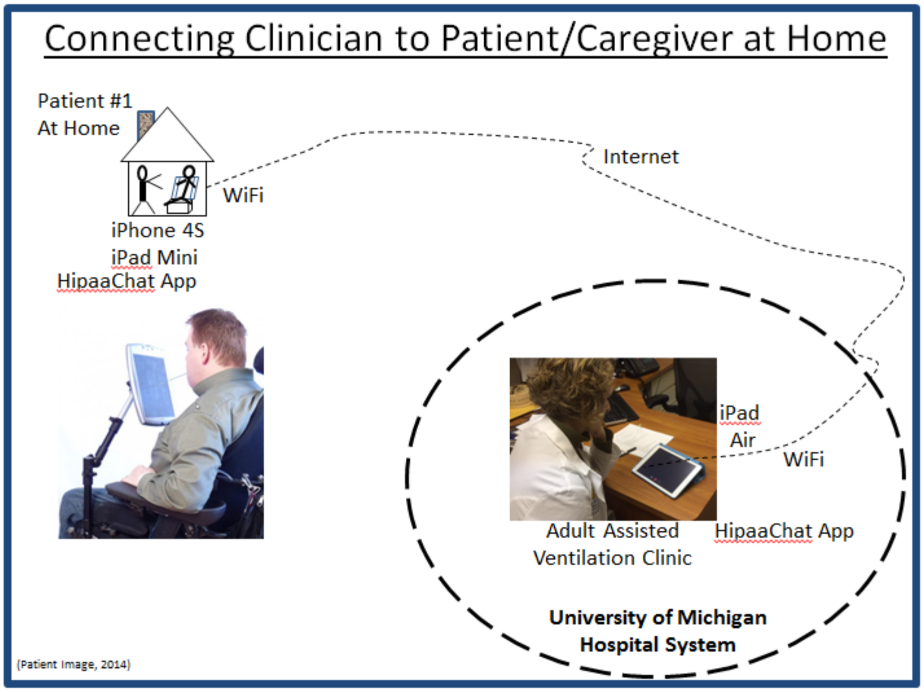


Figure 12. The clinic-to-patient/caregiver connection via an iPad Air to a mobile device.

The area of remote expert collaborative guidance discovered and utilized during the Zero Ventilator Knowledge Test and during clinical interactions with patients at home is not a new area of research, but it is an area that has been investigated and evolving for quite some time. In a guest editorial on telecommunications for remote medicine, the authors describe several terms that capture the idea of remote expert collaborative guidance in the terms *tele-consultation*, *tele-expertise*, *tele-monitoring*, *tele-assistance*, and *tele-surgery* as paradigms with novel potential (Jijiang, Jianqiang, & Rodrigues, 2015). There are a variety of medical areas where remote expert collaborative guidance is being applied and researched—some of those areas captured in the research literature are described next and include CPR, ultrasound guidance, surgical, and rehabilitation remote guidance.

Surgical telementoring was first mentioned in the literature around 1997. Laproscopic surgery was relatively new with a steep learning curve and training new inexperienced surgeons required an expert who could guide and assist to avoid complications. Laproscopic surgery utilizing telementoring was performed on seven patients by an inexperienced surgeon being telementored by a remote endoscopic specialist 3.5 miles away using videoconferencing over a T1 link all in real-time. All seven surgeries were successful and demonstrated the promise of telementoring for education and remote surgery expert guidance (Schulam et al., 1997).

In 2008, 40 patients receiving colon surgery were divided into two groups with 20 receiving open surgery and 20 performed using laparoscopic colon surgery with a telementoring specialist 60 km away. All surgeons were general surgeons—20 of whom were being guided remotely. If complications developed in the laparoscopic cases, they could revert to open surgery. Of significance, although the mentored cases took longer, the resulting hospital stays were shorter where 50% of the laparoscopy cases were discharged two days after the surgery due to the less invasive nature of laparoscopy (Schlachta, Kent, Lefebvre, McCune, & Jayaraman, 2009). A more recent laparoscopic study was published in 2016 on using endoscopic surgery of the skull base (neurology and otolaryngology) where telementoring was utilized between specialists at the University of Pittsburgh Medical Center mentoring surgeons at the University of Maribor in Slovenia. Mentored surgeons in 10 cases gave an average score of 9.5/10 and felt that mentoring decreased the time of these complex surgeries, resulting in greater tumor removal and preventing complications (Snyderman, Gardner, Lanisnik, & Ravnik, 2016). Another 2016 surgical study compared audio/videoconferencing directions given during surgery versus annotated images superimposed on the video to indicate directions and referred to as telestration. Time was shorted by 33%, greater accuracy was conveyed, and there was less miscommunication as a result of graphical annotations superimposed on video images during surgery (Budrionis, Augestad, Patel, & Bellika, 2013).

Sometimes telementoring can have mixed results as pointed out in Kirkpatrick et al.'s (2015) paper on hemorrhage simulation and the impact of a trauma surgeon telementoring medtechs remotely. Although the trauma surgeon telementored medtechs had greater confidence carrying out procedures such as incision, retraction, retraction direction and identifying site of bleeding, hemostasis, and closure on a *Cut Suit* simulation torso, they also took longer, used more sponges, and experienced more bleeding. The authors opinion was that telementoring may have a greater impact on complex procedures in the field where medtechs lack confidence or have tasks they are more hesitant to perform.

A 2008 by Yang et al. (n = 76) focused on guiding a bystander administering CPR using voice-only instruction versus voice and video. Results indicated that in the videoconferencing cases, greater ventilation volume was administered, there was a greater rate of maintaining an open airway, and there was a greater trend toward better noise pinching; however, this group also took longer to administer the first rescue breath and took longer to open the airway versus the audio only group (Yang et al., 2008).

Another area where remote expert guidance has been effective in enhancing remote patient care was telementoring ultrasound procedures. Two joint ultrasound telementoring sessions were performed between a California school of medicine and an Australian rural school of medicine to remotely guide remote students during ultrasound use (Winn et al., 2015). Remote students could see the instructor's ultrasound probe placement and the instructor's ultrasound output. The instructor, on the other hand, was able to see both their and the student's ultrasound outputs and use them to guide the remote student in improving transducer placement. The exercise was successful, demonstrating feasibility. The instructors liked the setup stating that the two feeds in going each direction demonstrated feasibility and the two ultrasound feeds they viewed were similar to their experience teaching in the classroom in person (Winn et al., 2015).

Another pediatric tele-ultrasonography telementoring study published in 2015 involved the diagnosis of appendicitis by comparing ultrasound (US) results by a resident, a telementored resident, and an on-site ultrasound expert in the diagnosis (Kim, Kang, Choi, Lim, Oh, & Chee, 2015). The sample size was n = 115 pediatric patients suspected of having an acute appendicitis were initially diagnosed by a resident using ultrasound. Subsequently, the same resident was telementored by an ultrasound expert who was simultaneously viewing the ultrasound image and the resident in a smaller image. This allowed the expert to observe the ultrasound transducer positioning by the resident and the resulting ultrasound image—this enabled the expert to provide telementoring advice to improve and optimize the resulting image and outcome. The remote expert was observing the ultrasound image and the resident using an iPhone 5S with an image of 1,136 x 640 pixels, a diagonal display size of 10.2 cm, and a contrast ratio of 800:1, and an LTE cellular connection. The following are a summary of ultrasound results comparing a resident (xx/), a telementored resident (/yy/), and an onsite US expert (/zz) (using the format xx/yy/zz, respectively): (a) US positive—true positive (33/36/36) and false positive (8/2/1), (b) US negative—false negative (3/0/0) and true positive (71/77/78). The resulting diagnostic values (for resident/telementored resident/US expert) are the following: for sensitivity (0.917/1.00/1.00), for specificity (0.899/0.975/0.987), for positive predictive value (0.805/0.947/0.973), and for negative predictive value (0.959/1.000/1.000). Clearly, the last two numbers in all these categories of measures were much closer between the telementored resident and the onsite US expert indicating that the non-telementored resident US performance was inferior. This study also pointed out the value of using mobile devices such as the smartphone iPhone 5S.

There is research on using Google Glass for videoconferencing in education, healthcare, and telementoring settings as an alternative to laptops, desktops, and even smartphones and tablets (Aungst & Lewis, 2015). A 2014 research project examined the use of Google Glass in bedside ultrasound telementoring where eighteen students were divided into three groups of six each to determine their ultrasound image quality using a GE Vscan portable ultrasound in a 3 minute image acquisition measuring cardiac ejection fraction. The first group received Google Glass telementoring from a remote expert (100% usable images, median quality of 7.5/10), the second group received in person/bedside training from the same expert (100%, 8/10), and the third control group did not receive any instruction (17%, 0/10). Both the telementored, and those trained in person by the ultrasound expert, matched very closely on capturing adequate images (100%) and average quality (7.5 vs. 8.0/10), while the *no instruction* group did poorly (17% adequate quality, none usable; Russell et al., 2014). Another 2016 surgery research project compared videoconferencing image quality of the Google Glass against an iPhone 5 for use in telementoring. Thirty-four attending surgeons rated Google Glass as fair (50%) to poor (50%) while 52.9% rated the Apple iPhone 5 as good. Although Google Glass is still in development, their estimate indicated it was not adequate for telementoring in the surgical setting (Apple iPhone vs. Google Glass = 82.4% vs. 26.5% with a $p < .0001$) with Google Glass having inadequate image quality for surgery telementoring (Hashimoto, Phitayakorn, Fernandez-del Castillo, & Meireles, 2016).

The final study by Anderson et al. (2016) discussed in this literature review on remote expert collaborative guidance involves using a tablet in a telestration or telementoring application to guide 20 (pre)medical students in making abdominal incisions versus the conventional approach. Telementored surgical incision placement error was less than the control (45% vs. 68%), fewer shifts of focus (44% vs. 86%), however, were performed more slowly.

Background on various aspects of remote ventilated patient management in general has been discussed up to this point. The focus now shifts to review the literature related to technology acceptance and behavioral health models, and the descriptive study of the approximately 670 mechanically-ventilated patients cared for by the Assisted Ventilation Clinic to capture their perceptions of ease of use, usefulness, their access to mobile devices, and their *intent to use* mobile devices in remote ventilated patient management.

Technology Acceptance and Health Behavior Models—Measuring *Intent to Use*

The initial and foundational step in conducting telemedicine research on remote ventilated patient management begins with developing a theoretical framework (Wade, Gray, & Carati, 2016). However, this is no simple task and an examination of the literature reveals multiple frameworks and categories of theories that have been applied to telemedicine research. Also, no single framework dominates the literature other than innovation diffusion theory, which is mentioned in approximately 11% of the time across reviewed literature reviewed in 2007–2008 (Gammon, Johannessen, Sørensen, Wynn, & Whitten, 2008) with an increase in the application of innovation diffusion theory to telemedicine research (Wade et al., 2016). Theoretical frameworks include: positivism, diffusion of innovations, technology acceptance models (TAM), health economics, and normalization process theory.

Telemedicine research also includes a broad spectrum of theories: systems and complexity, organizational change management, sociotechnical, constructivist, process, behavioral, and evaluation theories (Wade et al., 2016). Researchers often decide that no current theory captures the essence of their research setting and they create a new qualitative or quantitative model and theory for their particular project (Wade et al., 2016).

Telemedicine program developers, at the University of Michigan Medical Center, have discovered that specific telemedicine practices can vary greatly between different specialties (e.g., teledermatology vs. telepsychiatry). Teleradiology and teledermatology are highly focused on image data using store and forward techniques in their workflows. Remote telemedicine patient management for those with coronary heart failure may focus on remotely monitoring pulse-oximetry, weight, and blood pressure. In contrast, telepsychiatry, tele-primary care, or tele-pharmacy may primarily utilize videoconferencing for remotely interacting with the patient. No one model seems to fit all settings. As a result, many researchers have customized their own research models based upon the patient population, unique setting, and unique telemedicine capabilities that apply to their particular research project. Another aspect of telemedicine research was different population focus—one project may focus on clinicians' perception or acceptance of telemedicine while another may focus on the patients' perception or acceptance. Although there are many examples of models focusing on the use of electronic patient records, one example of this in the literature was a study by Maillet, Mathieu, and Sicotte (2015) that extends the unified theory of acceptance and use of technology (UTAUT) to apply specifically to medical records and the constructs most relevant to that setting (Maillet et al., 2015).

Understanding the relevant literature on theoretical frameworks and models was essential for developing a research model or conceptual framework that can be used to study patient readiness for remote ventilated patient management. In Chapter 1, the Patient *intent to use* conceptual framework based on Davis's (1989) TAM was presented in Figure 2, which was based upon the technology acceptance model (TAM) developed by Davis (1989). It provides a good starting point in examining the model literature evolution from before 1989 to the present. Based on the TAM model, our initial conceptual framework includes the following constructs: *perceived usefulness*, *perceived ease of use*, Access to Mobile Devices, and Patient *intent to use* Mobile Devices and Videoconferencing. Davis defines *perceived usefulness* as "the degree to which a person believes that using a particular system would enhance his or her job performance." Likewise, *perceived ease of use* is defined as "the degree to which a person believes that using a particular system would be free of effort" (Davis, 1989, p. 320).

There is a decision process that the patient/caregiver must traverse to come to the decision point of whether or not to accept technology as well as change their behavior in their healthcare (Figure 13). Remote ventilated patient management using mobile devices integrates both technology and health behavior—thus, the conceptual framework must integrate both technology acceptance and health behavior into the model.

Discovering and measuring Assisted Ventilation Clinic patient *intent to use* mobile devices and videoconferencing for remote ventilated patient care based upon access to mobile devices, *perceived usefulness,* and *perceived ease of use* seems like a straightforward problem to questionnaire via a sample and was depicted earlier in Figure 2. Examining the literature reveals many parallel and overlapping theoretical models trying to capture technology acceptance and health behavior. A single model as shown in Figure 2 was incomplete on its own. *Intent to use* mobile devices for remote home mechanical ventilation patient management involves both technology acceptance and health behavior among other factors or constructs, and measurement items that must be considered in the development of a composite model (Sun, Wang, Guo, & Peng, 2013). However, an examination of the research literature on selecting detailed variables and factors to incorporate into an acceptance model for this study quickly became unmanageable. A small snapshot of the problem encountered was captured in a book by Glanz, Rimer, and Viswanath (2008), *Health Behavior: Theory, Research, and Practice*, discussing the theory, research, and practice in health behavior and education while performing research for the second edition, "we reviewed 526 articles from twenty-four different journals in health education, medicine, and behavioral sciences, published from mid-1992 to mid-1994. Sixty-six different theories and models were identified, and twenty-one of these were mentioned eight times or more." There are an abundance of models and theories with a variety of constructs to explain technology acceptance and health behavior adoption around *intent to use*.

The difficulty arises in trying to include and capture all the relevant construct variables and factors to have predictive and correlational value while keeping the model as simple or at least as manageable as possible. In our case, with the approximately 670 Assisted Ventilation Clinic patients, we also have a variety of participants involved: clinicians (MD, NP, RT, LCSW, and nutritionist among others), family members, caregivers, and other social connections—each of these participants comprise a unique set of characteristics that can play a role in determining *intent to use*. One simplification or assumption was to group the patient, caregiver, and family members under the category *patient*. To survey patients, caregivers, and family members individually would significantly extend the scope of this project. A further assumption was that the patient was the manager of the care team being the most significant stakeholder in optimum care and can speak for the team either alone or in collaboration with their caregivers to answer the questionnaire.

Each patient must go through a decision process that is captured in Figure 13, titled Patient Decision Process in Technology Acceptance. There are many factors that together evaluated by the patient (both conscious and unconscious) that form their perceptions of telemedicine, using mobile devices and videoconferencing for remote patient care, *perceived ease of use*, *perceived usefulness*, and ultimately their *intent to use* the technology. This proposed study seeks to capture these factors in a conceptual model and determine the relationships between perceptions, demographics, access to mobile devices, and their *intent to use* these technologies in their care or to continue to use telephone-only support and clinical/clinician visits only.

The conceptual model must capture more than technology acceptance. Mobile devices and videoconferencing technology are obviously key components that impact acceptance. However, these patients have varying degrees of neuromuscular disorders and spinal cord injuries, which in many cases are life threatening. Thus, health behavior models and associated construct variables should also be included in the *intent to use* model. The discussion shifts to a review the literature to explore the various relevant models.

Over time, there has been an evolution in the research trying to capture the ultimate or ideal technology acceptance paradigm. In this study, proposing to use patient-owned mobile devices and videoconferencing to care for mechanically-ventilated patients was innovative. One of the pioneers in technological innovation acceptance was Everett M. Rogers whose papers and books focusing on the *Diffusion of Innovations* published in 1962, 1983, 1995, and 2003 are highly referenced primary sources on the topic (Rogers, 1962; Rogers, 2003). Rogers focused on how technology is adopted by various groups which is often depicted by a normal curve with acceptance occurring first by innovators, then early adopters, early majority adopters, late majority adopters, and laggards that are grouped around standard deviations and percent of people in each group (Rogers, 2003). Rogers proposed factors that influenced the diffusion or acceptance of technology were: observability (easy to identify and visible to all), trialability (easy to test, experiment), complexity (easy to use), compatibility (values, beliefs, norms, needs), and relative advantage (e.g., financial, social, utilitarian; Glanz et al., 2008; Rogers, 2003).

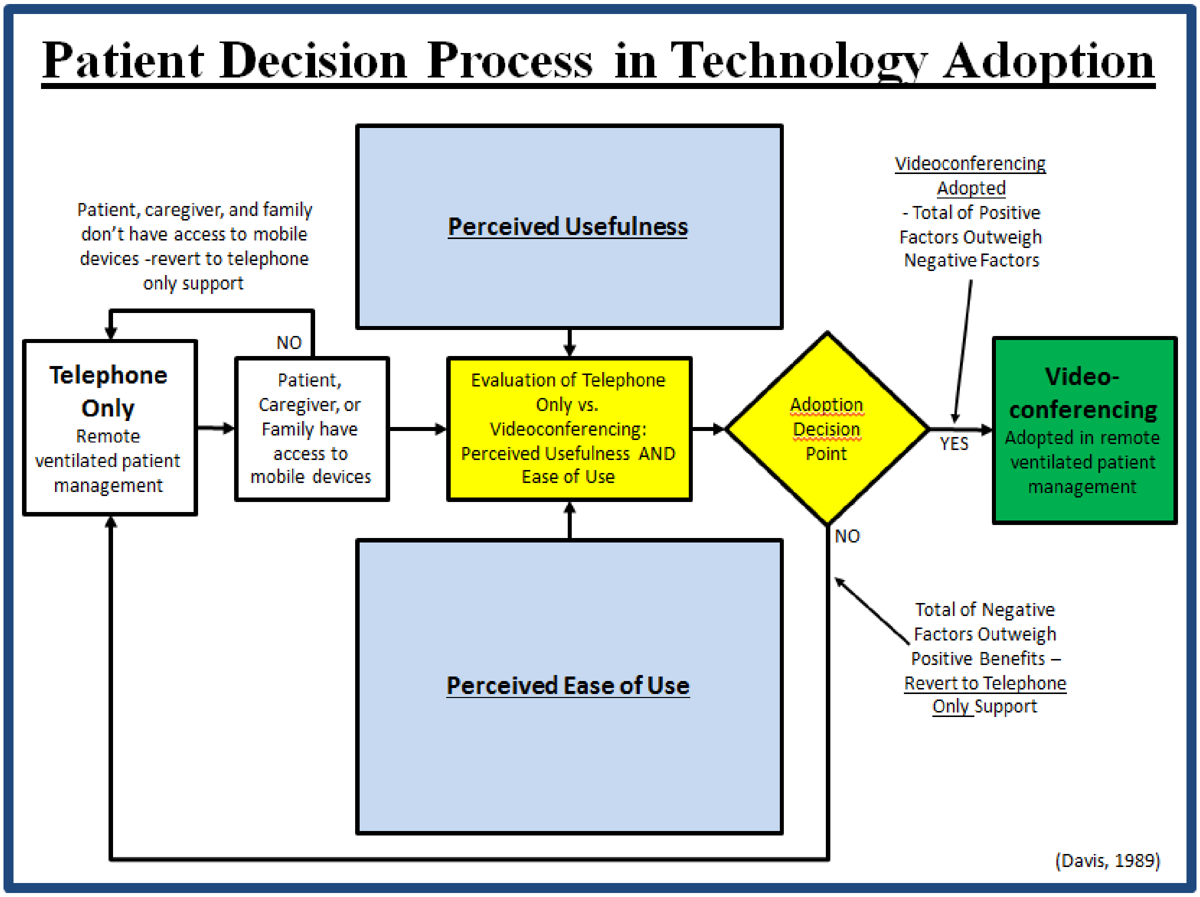


Figure 13. Patient decision process in deciding whether to use videoconferencing and mobile devices in their remote care.

There are several psychological models that examine influences on behavior. Bandura (1977) proposed a self-efficacy theory (SET) model based on a person's expectancy that they have an impact on outcomes to explain behavior. There are two closely related behavioral psychological models that evolved from Bandura's self-efficacy theory. They are the theory of reasoned action (TRA) and the theory of planned behavior (TPB; Madden, Ellen, & Ajzen, 1992). The TRA proposed by Ajzen and Fishbein (1977) state that *attitude* and *subjective norm* influence *behavioral intention* which in turn influences *actual behavior*. The TPB model builds upon the TRA model by adding *perceived behavioral control* as a variable influencing both *behavioral intention*, and *behavior* (Madden et al., 1992).

For many years, researchers have been trying to construct the perfect technology acceptance and health behavior model. Some of the most leveraged models are shown in Figure 14 as well as how they are interconnected and have evolved. Some of the most frequently referenced health behavior models include social cognitive theory (SCT; Bandura, 1977; Miller & Dollard, 1941; & Rotter, 1954), self-efficacy theory (SET; Bandura, 1977), the health belief model (HBM; Becker, 1974; Hochbaum, 1958; Janz & Becker, 1984; Glanz et al., 2008; Klein, Mogles, & van Wissen, 2013; Rosenstock, 1974; Sun et al., 2013), and the protection motivation theory (PMT; Prentice-Dunn & Rogers, 1986). Some of the most referenced technology acceptance models are also in the diagram and include theory of reasoned action (TRA; Montano, Kasprzyk, Glanz, Rimer, & Viswanath, 2008), theory of planned behavior (TPB; Ajzen, 1985, 1991), technology acceptance model (TAM; Davis, 1989), TAM 2 (Lee, Kozar, Larsen, 2003; Venkatesh & Davis, 2000; Sun et al., 2013), TAM 3 (Faqih & Jaradat, 2015; Venkatesh & Bala, 2008), the unified theory of acceptance and use of technology (UTAUT; Holden & Karsh, 2010; Sun et al., 2013; Venkatesh, Morris, Davis, Davis, 2003), and the UTAUT2 (Yuan, Ma, Kanthawala, & Peng, 2015). Two other models include the transtheoretical model (TTM; Klein et al., 2013) and the diffusion of innovations technology acceptance models (Rogers, 1962, 2003). The arrows in the diagram indicate that many of the theories have evolved from previous models and contain many of the same constructs with particular constructs added or deleted. The final box was labeled *The Ideal Technology Acceptance and Health Behavior Model*, which is yet to be determined. There are a variety of studies that combine constructs from a spectrum of models to develop an integrated model or combined model with the goal of developing greater predictability, especially in populations or projects that utilize technologies to promote or aid improved health behavior.

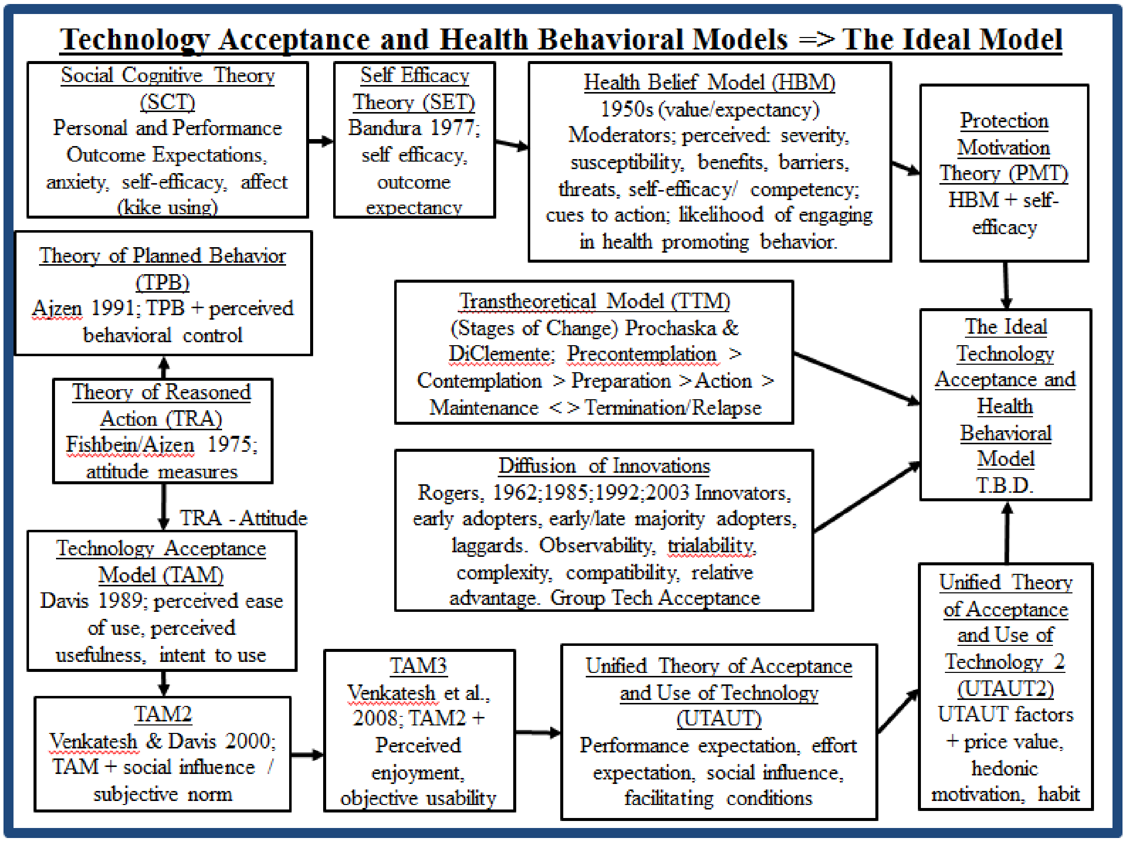


Figure 14. Technology acceptance and health behavioral model evolution.

Although not all inclusive across all literature on models, the models listed previously provide a good cross section of models. To help summarize these models, their abbreviations and relevant sources for each particular type of model are provided in Table 4.

Table 4

Health Behavior and Technology Adoption/Acceptance Models

Abbre-viation	**Model Name**	**Reference**
SCT	Social Cognitive Theory	(Klein et al., 2013)
SET	Self-Efficacy Theory	(Bandura, 1977)
SRT	Self-Regulation Theory	(Klein et al., 2013)
MM	Motivational Model	(Davis, Bagozzi, & Warshaw, 1992)
SEU	Subjective Expected Utility Theory	(Ronis, 1992; Sun et al., 2013)
HBM	Health Belief Model	(Becker, 1974; Glanz et al., 2008; Janz & Becker, 1984)
PMT	Protection Motivation Theory	(Prentice-Dunn and Rogers, 1986)
RPM	Relapse Prevention Model	(Klein et al., 2013)
TRA	Theory of Reasoned Action	(Fishbein & Ajzen, 1977; Sun et al., 2013)
TPB	Theory of Planned Behavior	(Ajzen, 1985, 1991)
TAM	Technology Acceptance Model	(Davis, 1989)
TAM2	Technology Acceptance Model 2	(Davis, 1989; Venkatesh et al., 2003)
TAM3	Technology Acceptance Model 3	(Faqih & Jaradat., 2015; Venkatesh & Bala, 2008)
UTAUT	Unified Theory of Acceptance and Use of Technology (UTAUT)	(Venkatesh et al., 2003)
UTAUT2	UTAUT2	(Venkatesh, Thong, & Xu, 2012; Yuan et al., 2015)
TTM/SOC	Transtheoretical Model / Steps of Change	(Klein et al., 2013; Prochaska & DiClemente, 1984)
CSE	Computer Self-Efficacy	(Compau & Higgins, 1995)
IDT	Innovations Diffusion Theory	(Rogers, 1962, 2003)
Myers-Briggs	Myers-Briggs Personality Inventory	(Briggs, 1976)

Each technology or health related model is associated with a set of core constructs. For example, three of the core constructs of TAM are *perceived ease of use*, *perceived usefulness*, and *intent to use*. The evolution of models is captured in Table 5, which lists construct themes in the first column, core constructs in the second column, and many different health belief and technology acceptance models across the top row. A matrix is created which captures core constructs versus various different models, indicating which core construct is captured by a particular model. The models are grouped into health behavior models, technology acceptance models, and combined models. Combined models integrate health behavior and technology acceptance and are particularly relevant to the Assisted Ventilation Clinic remote ventilated patient management program because of the spectrum of patients with respiratory issues using mechanical ventilation, mobile technologies (smartphones and tablets). Independent or modifying variables (or core constructs such as self-efficacy and attitude) can be grouped into broader categories or construct themes (e.g., *perceived ease of use*) that influence dependent variables such as *intent to use*.

Many challenges emerge in the creation and testing of these various technology acceptance and health behavior models. Models tend to evolve and incorporate various constructs from other models. However, wording is not always consistent across all models. Often a model is created for a particular population, such as college-aged people who are healthy, which makes it difficult to map onto other populations such as the Assisted Ventilation Clinic patients which have significant health issues. Technology is not always similar—mobile applications may be used in one setting while desktop/laptop computers accessing a website for educational materials or for entering patient home monitoring data may be the focus of another study. The predictive power of various models varies quite a bit and are described later.

There is a significant diversity in the evolution of technology acceptance and health belief/behavior models that is visible in the variety of constructs associated with the different models shown in Table 5. In general, health belief/behavioral models and technology acceptance models evolved along two different lines. Often, there are only a few and in some cases only one new construct that is added to a previous model to create a new model. With the introduction of ICT into healthcare, many new studies and models began to emerge which integrated both health belief/behavioral and technology acceptance models into new or combined models. These models captured the pure technology evaluation and acceptance as well as aspects of health belief and behavior that also played a part in the evaluation of new technology.

Table 5

Constructs Associated with Different Health Behavior and Technology Acceptance Models

Constructs	**Health Models**							**Technology Acceptance Models**									
	SCT	SET	SRT	MM	HBM	PMT	RPM	TRA	TPB	TAM	TAM2	TAM3	UTAUT	UTAUT2	TTM/SOC	IDT	Myers-Briggs
Performance Outcome/Expectation	X												X	X			
Perceives Control Over Outcomes	X																
Perceives Few External Barriers	X																
Confidence in One's Abilities	X																
Personal Outcome Expectation	X																
Anxiety (technology), Moods, Emotions	X										X	X					
Self-Efficacy, Able to Perform Act, Competency, Skills	X	X			X	X	X										
Affect (Like)																	
Act per se (Internal)				X													
Outcome Focus (External)				X													
Cognitive Representation			X				X										
Action Plan			X														
Coping Stage/Strategies			X				X										
Appraisal Stage			X														
Expectancy Value Theory; Cost Benefit Analysis					X	X											
Perceived Susceptibility, Vulnerability, Severity, High Risk					X	X	X										
Perceived Benefits					X												
Perceived Barriers (Internal/External)					X												
Response Efficacy, Response Costs						X											
Cues to Action					X												
Likelihood of Acting w/Health Promoting Behavior					X												
Attitude Impact								X	X								
Perceived Behavioral Control									X								
Perceived Usefulness										X							
Individual Differences										X							

Table 5 (continued)

Constructs	**Health Models**							**Technology Acceptance Models**										
	SCT	SET	SRT	MM	HBM	PMT	RPM	TRA	TPB	TAM	TAM2	TAM3	UTAUT	UTAUT2	TTM/SOC	IDT	Myers-Briggs
Intent to Use										X	X	X	X	X			
Actual Use									X	X	X	X	X	X			
System Characteristics										X							
Subjective Norm								X	X		X	X					
Image											X	X					
Job Relevance											X	X					
Output Quality											X	X					
Result Demonstrability											X	X					
Social Influence, Social Norms										X			X	X			
Facilitating Conditions										X			X	X			
Computer Self-Efficacy											X	X					
Playfulness (Intrinsic Motivation)											X	X					
Perceptions of External Control/Beliefs											X	X					
Experience, Skills											X						
Voluntariness											X						
Perceived Enjoyment												X					
Objective Usability												X					
Effort Expectancy													X	X			
Price Value; Pros/Cons														X			
Hedonic Motivation / Motivation														X			
Habit														X			
Pre-contemplation, Contemplation, Preparation, Action, Maintenance, Termination/Relapse															X		
Observability, Trialability, Complexity, Compatibility, Relative Advantage																X	
Personality Types: Extrovert, Introvert, Sensory, Intuitive, Thinking, Feeling, Judging, Perceiving																	X
Demographics*: Age, Gender, Race, Ethnicity, Education., or Income,*	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Note: Refer to Table 4 for model acronym definitions.

The models are grouped into two main categories of models, health belief/behavior models and technology acceptance models. Constructs are shown along the left column—

often the construct wording is different even though the concepts associated with the constructs are very similar with slight nuances. Examples include (a) social influence, social norms, and subjective norms; (b) observability, visibility, trialability, and demonstrability; or (c) self-efficacy, competency, or able to perform act.

The constructs listed in the first column of Table 5 are referenced in multiple manuscripts (refer back to Table 4). The various health models and technology acceptance models are associated with multiple constructs, sometimes overlapping with other models. The *X'd* boxes indicate that the construct in the left column is associated with the model listed in the top row. In the continuous search for the ideal model, researchers have adopted or adapted previous theoretical models to their particular research environment to improve the fit. The final result has been a broad spectrum of constructs that appear in the literature, which are used across the spectrum of models that have been and are being developed. No model has been able to universally capture all the factors that determine technology acceptance or health behavior change—this is obvious from the continuous variation in new models that appear in the literature. Different research settings present new or different technologies (e.g., electronic medical records, mobile applications, or monitoring devices) and different healthcare situations (e.g., healthy college students, elderly people at home, primary care checkups, or chronically ill patients at home with chronic heart failure). This diversity may make it impossible to create one universal model with a fixed set of constructs that totally capture predictive power to determine who actually adopts and uses technology in healthcare. To add to the complexity of model creation, the effect of personality type in the acceptance of technology and healthcare behavior to any great extent. A 2015 study by Barnett et al. explores the five-factor model personality traits as predictors of perceived and actual usage of technology. Another study by Xu Frey, Fleisch, and Ilic, (2016) explored the impact of personality traits on mobile app acceptance. Although Myers-Briggs was added to Table 5, investigating the impact of personality on technology acceptance and health behavior/belief is beyond the scope of this literature review and study but is explored in Svendsen, Johnsen, Almas-Sorensen, and Vitterso (2013).

One final proposed model not investigated in the literature is the risk analysis model used in information assurance. This model creates a trade-off process that integrates assets, threats, vulnerabilities, attacks, counter-measures, residual risk, and so on that maps in many ways to the constructs in models previously presented. Trade-offs is a key component active in technology acceptance and health behavior adoption. Although mentioned here as an area for future research, the risk analysis model is beyond the scope of this literature review and research study.

The complexity and diversity of technology and health models has not stopped researchers from developing combined models. This literature review narrows the focus to eighteen papers that include combined models—attempts to integrate technology and healthcare adoption constructs and models into a single integrated model. Although not a complete list of combined models, the references listed in Table 6 provide a representative collection of studies that attempt to integrate the constructs of technology and health models into one model. Again, there is diversity in the models due to the variation subject matter in each study. Some of the technologies include a mobile coaching system (Klein, Mogles, & van Wissen, 2013), mobile devices (Faqih & Jradat, 2015), health apps (Yuan et al., 2015), healthcare information systems (Pai & Huang, 2011), tablet use (Magsamen-Conrad, Upadhyaya, Joa, & Dowd, 2015), mobile health services (Nisha, Iqbal, Rifat, & Idrish, 2015), and other technologies. These studies also span a variety of health issues including the testicular exam (McClenahan, Shevlin, Adamson, Bennett, & O'Neill, 2007), home telehealth with older users (Cimperman, Brenčič, & Trkman, 2016), coaching for therapy adherence (Klein et al., 2013), and aging in place (Peek et al., 2014).

Table 6

18 Combined Models Research Papers Used for Extracting Technology Acceptance/Health Behavior Constructs

Abbreviation	Combined Models Research Papers	References
HITAM	Development of a Health Information Technology Acceptance Model Using Consumer's Health Behavior Intention	Kim & Park, 2012
ETAM	Modeling the Acceptance of Clinical Information Systems Among Hospital Medical Staff: An Extended TAM Model	Melas, Zampetakis, Dimopoulou, & Moustakis, 2011
IMITAHC	Towards an Integrated Model of IT Acceptance in Healthcare	Moores, 2012
Sun Model	Understanding the Acceptance of Mobile Health Services: A Comparison and Integration of Alternative Models	Sun et al., 2013
CombiModel	An Intelligent Coaching System for Therapy Adherance	Klein et al., 2013
MCTAM3	Assessing the Moderating Effect of Gender Differences and Individualism-Collectivism at Individual-Level on the Acceptance of Mobile Commerce Technology: TAM3 Perspective	Faqih & Jradat, 2015
TAM/ 2UTAUTBP	The Technology Acceptance Model: Its Past and its Future in Health Care	Holden & Karsh, 2010
UTAUT2	Keep Using my Health Apps: Discover Users' Perception of Health and Fitness Apps with the UTAUT2 Model	Yuan et al., 2015
STAMV	The Technology Acceptance Model: Past, Present, and Future	Lee et al., 2003
TAMHIT	Applying the Technology Acceptance Model to the Introduction of Healthcare Information Systems	Pai & Huang, 2011
WTAHC	An Empirical Study of Wearable Technology Acceptance in Healthcare	Gao, Li, & Luo, 2015
IHBMTAM HRIU	Integrating Health Belief Model and Technology Acceptance Model: An Investigation of Health-Related Internet Use	Ahadzadeh, Sharif, Ong, & Khong, 2015
AgeInPlace SysRev	Factors Influencing Acceptance of Technology for Aging in Place: A Systematic Review	Peek et al., 2014
TabletUTAUT	Bridging the Divide: Using UTAUT to Predict Multigenerational Tablet Acceptance Practices	Magsamen-Conrad et al., 2015
PrivacyCalc Mod	Examining Individuals' Acceptance of Healthcare Wearable Devices: An Empirical Study from Privacy Calculus Perspective	Li, Wu, Gao & Shi, 2016
MobileMod	Mobile Health Services: A New Paradigm for Health Care Systems	Nisha et al., 2015
ExtUTAUT Mod	Analyzing Older Users' Home Telehealth Services Acceptance Behavior: Applying an Extended UTAUT Model	Cimperman et al., 2016
TesticTestMod	Testicular Self-Examination: a Test of the Health Belief Model and the Theory of Planned Behavior	McClenahan et al., 2007

The goal continues to be developing a model for remote mechanically-ventilated patient management. In pursuit of that model, the constructs of these eighteen focus papers is captured in Table 7. The attempt was made to group the constructs when possible into a single category of closely related constructs. The totals for various constructs (and groupings) are tallied down the far right column. These were useful in creating a customized model for mechanically-ventilated patient management later on.

Table 7

Construct Frequencies Across 18 Studies Using Combined Models (TAMs & HBMs)

Constructs Used in Combined Models in 18 Studies - Technology Acceptance Models & Health Behavior Models	**Kim & Park, 2012**	**Melas et al., 2011**	**Moores, 2012**	**Sun et al., 2013**	**Klein et al., 2013**	**Faqih & Jradat, 2015**	**Holden & Karsh, 2010**	**Yuan et al., 2015**	**Lee et al., 2003**	**Pai & Huang, 2011**	**Gao, et al., 2015**	**Ahadzadeh et al., 2015**	**Peek et al., 2014**	**Magsamen-Conrad et al., 2015**	**Li et al., 2016**	**Nisha et al., 2015**	**Cimperman et al., 2016**	**McClenahan et al., 2007**	**TOTALS**
Perceived Usefulness: feature demands, objective usability	1	1	1	1		1	1		1	1		1	1						10
Social influence, subjective norm beliefs, individualism-collectivism, social presence, prestige, image, MD influence, cues to action	1			1	2	3	4	1	4		1		3	1	1	1	2	2	27
Quality (output, information, service, system)			1			1	1			3						1			7
Result demonstrability, visibility, trialability/observability						1	1		3										5
Perceived Ease of Use: effort expectancy, complexity, habit, voluntariness, support)	1	1	2	1		2	2	2	2	1	1	1	1	2		1	1		21
Self-efficacy, perceived behavioral control, beliefs	1		1	2	1	1	2		1		1							2	12
Playfulness, hedonic motivation, enjoyment						1		1	1		1								4
Attitude	1			1	1		1		1			1						1	7
Perceived benefit (safety, independence, reduced burden, informativeness, trust, security, legal protection, accuracy, timeliness, need for technology, physician specialty, informative)		1	2										5		3	1	1	1	14
Perceived threats, barriers, privacy risk, threat appraisals, health info sensitivity					2						1	1	1		2			1	8
Perceived susceptibility/vulnerability	1			1	1						1	1						1	6
Perceived seriousness/severity, high risk	1			1	2						1	1						1	7
Behavioral/adoption intention to use, commitment, motivation (health), personal innovativeness	1	1		1	2	1	1	1		1	1			1	1	1	1	2	16
Behavior (usage), actual use (various types of use), past behavior						1	1					3			1	1		2	9
Experience, knowledge, skills		1	1		1								1	1	1				6
Compatibility, job relatedness/relevance, functional congruence, reliability	1						1		2		1				1				6
Performance expectancy, response efficacy, perceived efficacy, perceived external control, ineffective, control beliefs, response cost				1		1	2	1			1		2	1		1	1		11
Facilitating conditions, response Cost				1			1	1						1		1	1		6
Pros/cons, price/value, relative advantage					1			1	1										3
Emotions, mood, anxiety (technology)					2	1											1		4
Awareness; health consciousness, health status					1							1	1		1				4
Innovativeness, coping strategies, alternatives					1				1				1		1				4
Tech concerns: monthly expense, complexity, high cost, stigmatization, impracticality, negative effect on health, forget/lose tech, burden caregivers, false alarms, obtrusiveness						1			1				7						9

The diversity and distribution of construct counts in Table 7 demonstrates that there is no single universal model that integrates technology acceptance and health behavior into a single set of constructs for all types of research. In many ways, it seems that each study included constructs that seemed most applicable to their particular technology and health setting or configuration. It is clear that some categories had larger counts and may give an indication that those constructs are most commonly selected across all technology + healthcare settings—some that stand out are *perceived usefulness*, *social influence*, *perceived ease of use*, *self-efficacy*, *perceived benefit*, *perceived threats/susceptibility/ severity/seriousness/high risk*, *behavioral adoption/intention to use*, *perceived expectancy/efficacy/control/response*, and *technology concerns*. Narrowing this large list of constructs down to those most applicable to remote mechanically-ventilated patient management was the next step that was pursued in Chapter 3: Methodology.

Summary of the Literature Review

The introduction of smartphones and tablets (e.g., Apple iPhones/iPads and Android smartphones/tablets) into healthcare, referred to as m-Health, has opened new possibilities for remote patient care. The pervasiveness of mobile devices is captured in the results of a 2014 U.N. study which found that of the world's 7 billion people, 6 billion have mobile phones while only 4.5 billion have access to working toilets (PhonesThrones, 2014).

There are thousands of downloadable m-Health apps that can be downloaded from the Apple iTunes Store or the Android download site. Claudia Tessier (Moumtzoglou, 2016) described m-Health by grouping applications into 12 clusters or application areas. The clusters include (a) patient communications, (b) access to web-based resources, (c) point of care documentation for physicians and clinicians, (d) disease management, (e) point of care education, (f) professional communication, (g) administrative applications, (h) financial apps, (i) ambulance/EMS, (j) public health, (k) research, and (l) body area networks (BANs). Mobile applications are used for a variety of health applications, disease types, different functions (e.g., display, data collection, communication, guidance). Although there are many applications available for download, those that are most beneficial and popular for healthcare are limited (36 applications comprised 50% of all downloads).

Neuromuscular disorders and spinal cord injuries can be deadly for patients, expensive to treat and provide care, can be progressive, and can require invasive mechanical ventilation including a tracheostomy. There are over 30 types of muscular dystrophy and over 100 neuromuscular disorders. In addition to the financial burden, there is the caregiver burden in many cases where the patient requires 24/7 care. Moving mechanically-ventilated patients to their homes is beneficial for them and lowers costs. However, remotely caring for MV patients can be complex often resulting in unnecessary visits to the emergency department where they may receive unnecessary treatments or hospitalization.

Mechanical ventilators are complex devices. When we consider technology acceptance, often there is no voluntary aspect—if the patient wants to survive, they may require a ventilator. The complexity of ventilators can become evident when examining the multiple screens, 216 or more settings options, and meshing the specific settings to the patient’s current condition or what to do when unexplained alarms sound.

The Assisted Ventilation Clinic provides is an alternative to the patient going to the emergency department when a potential emergency arises. Regular visits to the clinic often curb these emergencies, but when they happen remotely, the Assisted Ventilation Clinic provides remote telephone-only support to patients. Telephone-only support can be supplemented with videoconferencing which is the focus of this descriptive study. Videoconferencing quickly provides additional information beyond what can be communicated verbally. Although mobile devices are pervasive, using them to care for remote ventilated patients is limited.

Researchers' first instance using videoconferencing to care for mechanically-ventilated patients dates back to a paper published by Miyasaka et al. (1997). Information and communication technology has evolved significantly since 1997 to the point where Casavant et al. (2014) used Vidyo videoconferencing software on desktop computers to remotely care for pediatric patients on mechanical ventilators. Although Casavant et al. (2014) mentioned the potential use of handheld devices, there was no evidence that they actually tested using mobile devices. The most recent of using mobile devices to remotely care for mechanically-ventilated patients is documented in Bell et al. (2016), where remote respiratory therapists (RTs) were connected with mechanically-ventilated pediatric patients in a remote ICU with a comparison of 20 face-to-face visits versus 20 remote RTs evaluating the same patient only remotely using mobile devices. Although the sample size was small, results were positive and demonstrated the potential of remotely caring for mechanically-ventilated patients remotely.

An interesting artifact of caring for mechanically-ventilated patients remotely was observed during Zero Ventilator Knowledge tests where a person who had never seen a ventilator was able to be successfully guided by a remote nurse practitioner and respiratory therapist. The immediate feedback provided by videoconferencing allowed the remote clinicians to guide the person through complex ventilator steps and troubleshooting to resolve alarms and adjust ventilator pressure settings. This has great potential in many other settings and will be explored further in future research.

The final section in the literature review focused on developing a questionnaire or measurement instrument to determine patients' and caregivers' *intent to use* mobile devices in remote mechanically-ventilated patient management. Because caring for mechanically-ventilated patients remotely involves both technology acceptance and health behavior/beliefs, models from both areas are relevant to developing a measurement instrument. Health behavior models include SCT, SET, SRT, MM, HBM, PMT and RPM models. Technology acceptance models include TRA, TPB, TAM, TAM2, TAM3, UTAUT, UTAUT2, TTM/SOC, and finally, Roger's innovation diffusion theory (IDT). To emphasize the challenge of identifying all the constructs relevant to predicting health behavior, technology acceptance, and *intent to use* the technology, Myers-Briggs personality types were also mentioned, which opened a research area beyond the scope of this literature review and research. Although there is much overlap in these models, there is also significant variation in which constructs are used in individual models. The literature review was narrowed to 18 papers that focused on the integration of health-related models with technology acceptance models in single models. Unfortunately, there was a great deal of difference between these integrated models. The frequency of construct usage was calculated across the 18 studies which indicated that some individual constructs were common across all 18 studies. Some of the constructs or themes that were most used included *perceived usefulness*, *social influence*, *perceived ease of use*, *self-efficacy*, *perceived benefits*, *perceived threats* (including *susceptibility*, *vulnerability*, *seriousness*, *high risk*), and *behavioral adoption/intention*. Other constructs could possibly be combined to reduce the number of construct themes (e.g., self-efficacy, performance expectancy, perceived external control, response efficacy). Although technology concerns were high, most of the count came from one study Peek et al. (2014). Another area of constructs that was hard to categorize included emotions, mood, attitude, anxiety, and consciousness, which seemed to be more internal influences which could be formed during years of past experience and beyond the reach of immediate measure. These effects are included in TAM2 and may be more appropriately explored by psychoanalysis.

Finally, creating an integrated model of all the constructs included in the 18 focus papers discussed previously would produce a conceptual technology acceptance/healthcare behavior model that is too complex to analyze in this study (refer to Appendix B, C and D). There are a variety of constructs that have been applied in research involving both health behavior or belief adoption and technology acceptance models. This wide spectrum of constructs used in these models doesn't provide a single model that can be universally applied to all patient populations using all types of information and communication technology. In an attempt to narrow the constructs to those most relevant to the Assisted Ventilation Clinic patient population, from the 18 previously analyzed papers, four of these papers most closely match the environment of remote ventilated patient management discussed previously have been selected (Sun et al., 2013; Kim & Park, 2012; Yuan et al., 2015; and Gao et al., 2015). These studies focus on key aspects that make them attractive as potential models to apply in this research. They include: mobile devices, health care models (e.g., HBM, SEU, PMT, TRA, and TPB), and technology acceptance models (e.g., TAM, TAM3, UTAUT, and an extended UTAUT2). These studies reviewed the literature and consolidated the number of constructs to around a dozen or less in their models. The constructs, the definitions, and reference sources of the definitions for these four papers are included in Appendix E. The list of constructs included in only these four papers is still too extensive to list in a single questionnaire (Appendix F), but they do provide a basis for measurement item development in the questionnaire.

Chapter 3: Methodology

The primary purpose of this study was to gather, analyze, and report the relevant results based on the perceptions of the Michigan Medicine adult Assisted Ventilation Clinic patients and caregivers in order to discover their existing level of access to mobile devices and determine the level of patient and caregiver *intent to use* these mobile devices in remote mechanically-ventilated patient management. Information gathered can be valuable in planning and providing telemedicine services for the Assisted Ventilation Clinic patient population and improve their remote care. As eHealth services are implemented by healthcare organizations, it was valuable to also examine the response of the patient and caregiver populations' responses to these new services.

The literature review in Chapter 2 provides an expansive view of research efforts relevant to remote ventilated patient management using mobile devices. The goals of this chapter are to describe the process that was used to (a) converge relevant research models, constructs, and measurement questions into a questionnaire that can be used to gather data from Assisted Ventilation Clinic patients; (b) collect data using this questionnaire; and (c) analyze the data to discover and compile results and findings from the study, which are presented and discussed in subsequent Chapters 4 and 5. This project was based on descriptive research techniques using quantitative methods where both descriptive and inferential statistics were used in analyzing the data (SRM, 2016).

Study Type and Design

This descriptive study involved developing and distributing a questionnaire to the approximately 670 patients in the Michigan Medicine system supported by the adult Assisted Ventilator Clinic. Medical record access was not required—this questionnaire only collects anonymous information relative to the telemedicine *intent to use* construct of these patients and their caregivers. However in addition to perceptual questions related to using mobile devices, demographic questions were also asked to discover the patient's medical conditions, age, distance from the Assisted Ventilation Clinic, distance from the nearest emergency department, amount of time the patient was on a mechanical ventilator each day, and whether they have a tracheostomy. Data were collected online through Qualtrics, a PHI compliant and approved tool for collecting survey data using an Internet link to the questionnaire or via a paper based questionnaire that was subsequently be entered into the Qualtrics system.

A general roadmap for this study was presented in Figure 15, which provides a process map including steps beginning with the questionnaire creation and proceeding through data collection, analysis, and finally, compiling the results.

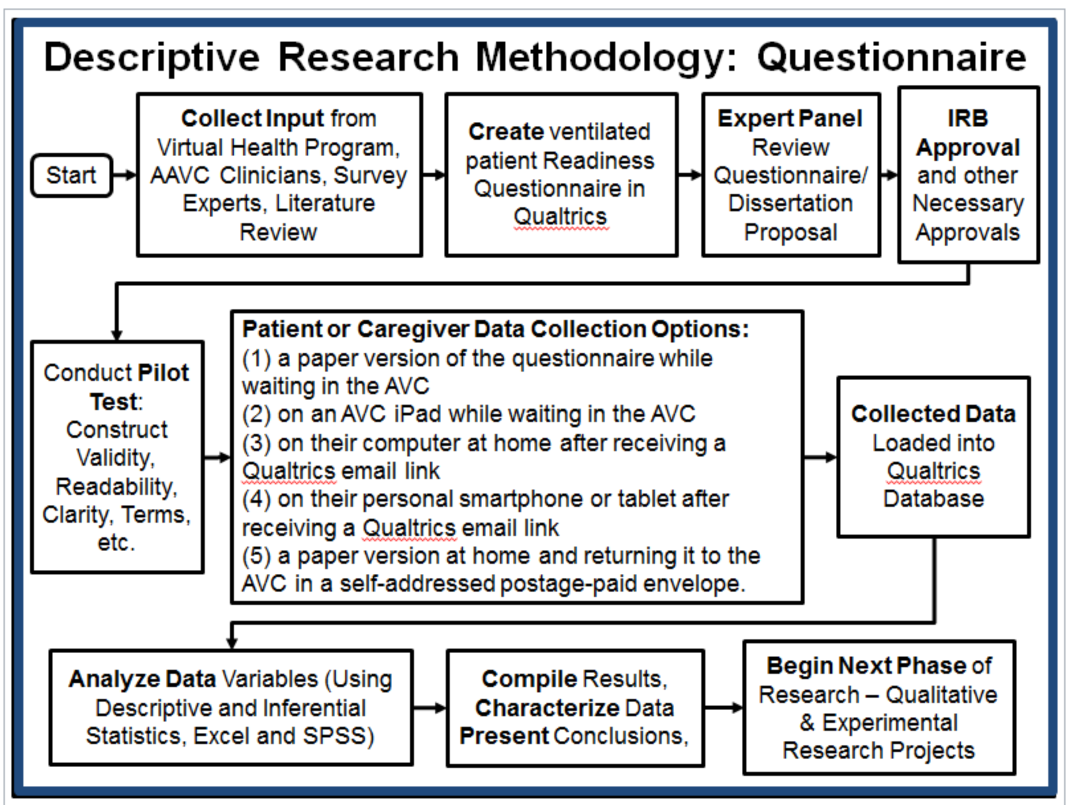


Figure 15. Descriptive questionnaire preparation, patient selection, questionnaire delivery, and data collection process.

The format and content of the questionnaire was developed using input from the literature review, Virtual Health experts, staff within the Adult Assisted Ventilation Clinic, and survey experts including the members of the dissertation committee. The questionnaire was created in Qualtrics which is a HIPAA/HITECH compliant data collection instrument, storage, and reporting tool. In cases where paper-based questionnaires were used, the data from these instruments was loaded into Qualtrics to integrate all the data in a single PHI compliant database.

Population and Sample

The primary pool of subjects comprises approximately 670 ventilated patients (and their caregivers) cared for by the Assisted Ventilation Clinic which is part of the University of Michigan Internal Medicine Pulmonary Department. This study sampled some of the approximately 670 mechanically-ventilated patients in the Michigan Medicine system cared for and supported by the adult Assisted Ventilator Clinic by using a questionnaire. This population includes both invasively and non-invasively ventilated patients. A sample size of about 150 (of the approximately 670 patients plus their caregivers) was recruited to be part of the study—assuming they provided consent. The minimum sample for 500 patients in a population for adequate statistical power is approximately 50% or 250 respondents (Leedy & Ormrod, 2005). Although a census of all patients and caregivers was not feasible, the literature indicates that a sample of n = 150 provides adequate power for the study (Bashshur et al., 2014; Bashshur et al., 2015).

The Questionnaire—Development of the Survey Instrument

This descriptive study used a questionnaire to collect data from all the approximately 670 mechanically-ventilated patients (and their caregivers) supported by the Michigan Medicine Assisted Ventilation Clinic. This is a diverse population located within and outside Michigan. It cannot be assumed that all patients and caregivers have access to smartphones, tablets, laptops, or desktop computers. The questionnaire appeared the same to all patients and caregivers, whether the paper version or the online version was used. This study explored five modes of questionnaire delivery to the patients/caregivers: (a) a paper version that was completed in the Assisted Ventilation Clinic, (b) an online version accessible using a QR Code or shortened URL in the Assisted Ventilation Clinic, (c) a Qualtrics link in the patient portal, (d) a Qualtrics link located on the University of Michigan research website, and (e) a phone call to the patient/caregiver where respondent answers are collected over the phone and loaded into Qualtrics manually. Whether or not a patient or caregiver had Internet access did not limit their participation in the study. Ultimately, due to various constraints, two methods were used for data collection, a paper version and an online version with an iPad provided in the clinic for respondents to use if they desired.

Although creating a short video clip to allow everyone to grasp the concept of telemedicine was discussed, a short explanation using the six videoconferencing pictures in the questionnaire, and a short demo using a smartphone were used instead due to limited resources and time.

Completing the questionnaire instrument required several steps including expert panel input, committee input, and a pilot test. Figure 16 provides the steps that were followed in creating, refining, validating, a pilot test, testing the reliability, obtaining IRB approval (of both EMU and U of M), and refining the final questionnaire.

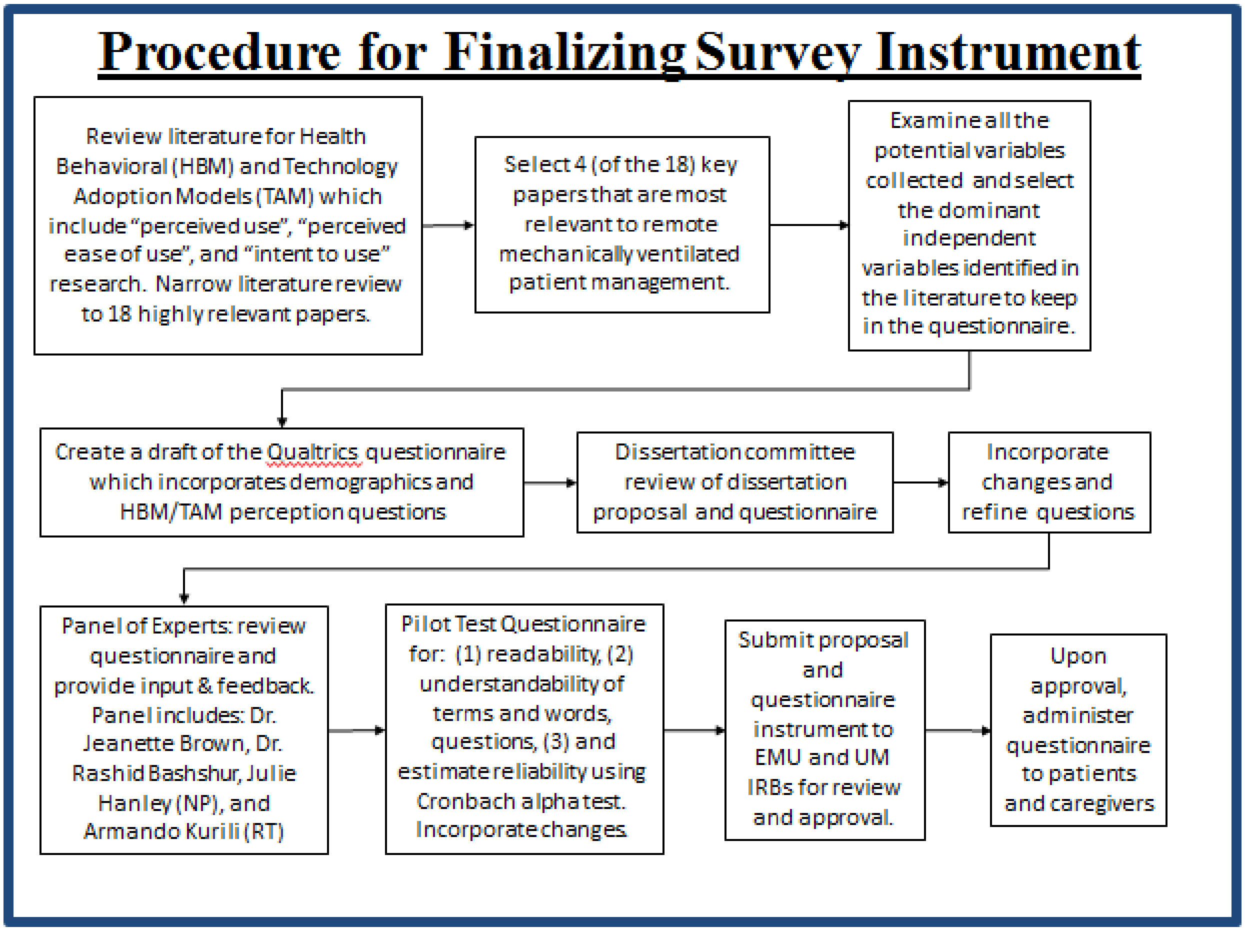


Figure 16. Procedure for finalizing the questionnaire instrument.

Although most people have access to a telephone, it was unknown how many people own or have access to more sophisticated mobile devices. This study captured data through the questionnaire. Some of the information gathered includes: Patient or caregiver categorization, age, sex, distance to emergency department and Assisted Ventilation Clinic, amount of time/day on a ventilator, disease types, ownership or access to a mobile devices between 8:00 a.m. and 5:00 p.m., Monday–Friday, and is there cellular, WiFi, or Internet access in the patient's home.

Procedure for finalizing the questionnaire. The following steps were followed to create and finalize the patient questionnaire.

- Collect questionnaire question input from Dr. Jeanette Brown (MD, PhD), Julie Hanley (NP), and Armando Kurili (RT). Also, they reviewed the paper and online versions of the questionnaire.
- Review literature and other ventilation patient surveys; integrate appropriate constructs, sub-constructs, and measurement item questions into the questionnaire.
- Review literature for *perceived use*, *perceived ease of use*, *access*, and *intent to use* research and incorporate relevant independent variables into questionnaire.
- Examine all the aggregated independent variables and constructs collected above and select the dominant variables identified in the literature to remain in the draft questionnaire.
- Create and refine the questions and incorporate them into the draft Qualtrics questionnaire online instrument and also in printed format as well.
- Obtain Eastern Michigan University and the University of Michigan IRB approvals.
- Conduct a pilot test which will provide feedback and data allowing Cronbach's coefficient alpha calculations for each construct factor to measure reliability, test readability, and understandability. An open ended question was provided at the end of the pilot questionnaire to allow for open-ended feedback from pilot questionnaire participants.
- Collect questionnaire suggestions, corrections, and improvements from the expert panel and dissertation committee members.

The conceptual model. An integrated conceptual model based upon all the constructs discovered in the literature review focusing on the 18 relevant HBM/TAM papers is captured in Appendix D. This model was too complex for this study—for example, using only three questions (measurement items) per construct, a 50-construct model would yield 150 questions. This was not an acceptable questionnaire length to use with the remote mechanically-ventilated population and would lead to significant respondent burden (a 150 questions requiring only 10 seconds per question would result in approximately 25 minutes to complete). An article on Qualtrics website provides tips for a successful survey—(a) take no more than 15 minutes to complete (otherwise dropouts increase, people stop paying attention, and some may get angry), (b) use scales, (c) maintain consistent coding scales, and (d) make the survey specific for the respondents and explain what's in it for them (Smith, 2012). Forty questions total with an average of 20 seconds per question takes about 13 minutes to complete. Many of the questions can be completed in 5 to 10 seconds leaving more time for questions requiring more time and thought. The goal was no more than 40 questions for this questionnaire.

A compromise can be reached with the selection of only four key papers (of the 18) that apply most directly to the Assisted Ventilation Clinic population. The foundational paper first used to build a workable conceptual model was by Sun et al. (2013), which points out the need to adapt the technology acceptance model to the healthcare context (Holden & Karsh, 2010). The Sun et al. (2013) model was created by examining the constructs included in the health models (HBM, PMT, SEU, and TRA) and technology acceptance models (TRA, TPB, IDT, TAM, TAM2, and UTAUT). The final model developed by Sun et al. (2013) contains the following 11 constructs: *intention to adopt*, *attitude*, *subjective norm*, *perceived* *behavioral control*, *perceived usefulness*, *perceived ease of use*, *perceived vulnerability*, *perceived severity*, *response cost*, *response efficacy*, and *self-efficacy* (Sun et al., 2013, p. 193).

A second included paper by Kim and Park (2012) added *health belief & concerns*, *perceived susceptibility*, *perceived seriousness*, and *reliability*. In many ways, these four sub-constructs are similar to *susceptibility*, *seriousness*, *vulnerability*, and *severity*, which are listed in the Sun et al. (2013) construct list. Kim and Park's *reliability* was the only unique sub-construct included in addition to the Sun et al. (2013) list.

The third included a paper by Yuan et al. (2015), which added *performance expectancy*, *effort expectancy*, *social influence*, *facilitating conditions*, *price value*, *hedonic motivation*, and *habit*. *Performance* and *effort expectancy* to the research model, as well as *social influence*, which was combined with *social norm* into a single term, *social influence*. Remote patient management was an emergent environment; thus, recreational, playfulness, or enjoyment type terms contained in *hedonic motivation* were not included in the research model. *Price–value* was also not included because the concept it provides was included in *response efficacy/cost* which are already included in the model.

The fourth paper by Gao et al. (2015) added *functional congruence*, *perceived privacy risk*, and *product type* to the previously used constructs.

To narrow the number of constructs in the model, an intermediate conceptual model based upon four of the 18 key papers that seem most applicable is shown in Figure 17. After evaluating the constructs from the four selected papers, the constructs in the intermediate model include: *perceived ease of use*, which included sub-constructs *visibility*, *attitude*, *effort expectancy*, *performance expectancy*, *self-efficacy*, and *external support; perceived* *usefulness*, which included the sub-constructs *reliability*, *health beliefs* (which includes *vulnerability*, *susceptibility*, *seriousness*, and *severity*), *response efficacy*, *experience*, *response cost*, and *social influence/norm*; and finally, *intent to use*, the key variable of the study. Actual behavior was added to the model for completeness only and was not a construct that was analyzed in this study. Demographics are also included in Figure 17, were detailed in the questionnaire, and also presented in the final conceptual research model.

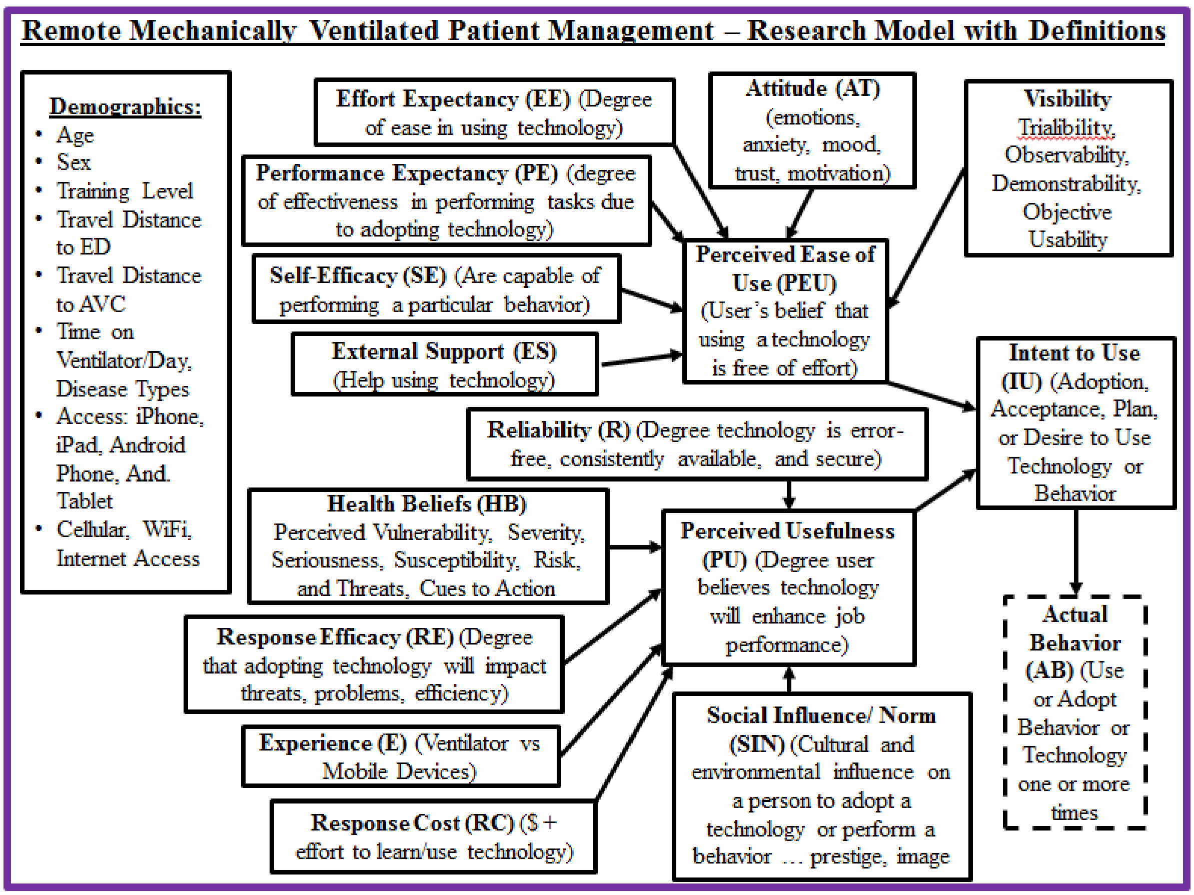


Figure 17. Intermediate conceptual model based upon four (of the 18) key papers.

The next phase of the questionnaire development was to create measurement items or questions to measure the impact of these constructs. The overall goal remains to measure *intent to use* based upon the relationship between the constructs grouped in *perceived ease of use* and *perceived usefulness*. Measurement items (questions) from the original four studies presented in the literature review were gathered (if they had questions listed in the paper) and compiled. Measurement items were then filtered and adapted to the Assisted Ventilation Clinic population. Detailed references and expanded questionnaire are located in Appendix C and F.

After refining the model in Figure 17, the final research conceptual model is shown in Figure 18. Questions, constructs, and measurement items were examined for overlap and redundancy, and it was determined that the model could be simplified as shown in Figure 18 with demographics, *perceived ease of use* (which includes sub-constructs *effort expectancy*, *self-efficacy*, *attitude*, and *visibility*), *perceived usefulness* (includes the sub-constructs *performance expectancy*, *response cost*, *social influence/norm*, and *health beliefs*), and the final dependent variable and construct, *intent to use*. The measurement item key words listed in each construct box were reduced further to allow a reduction in measurement items to 36 questions.

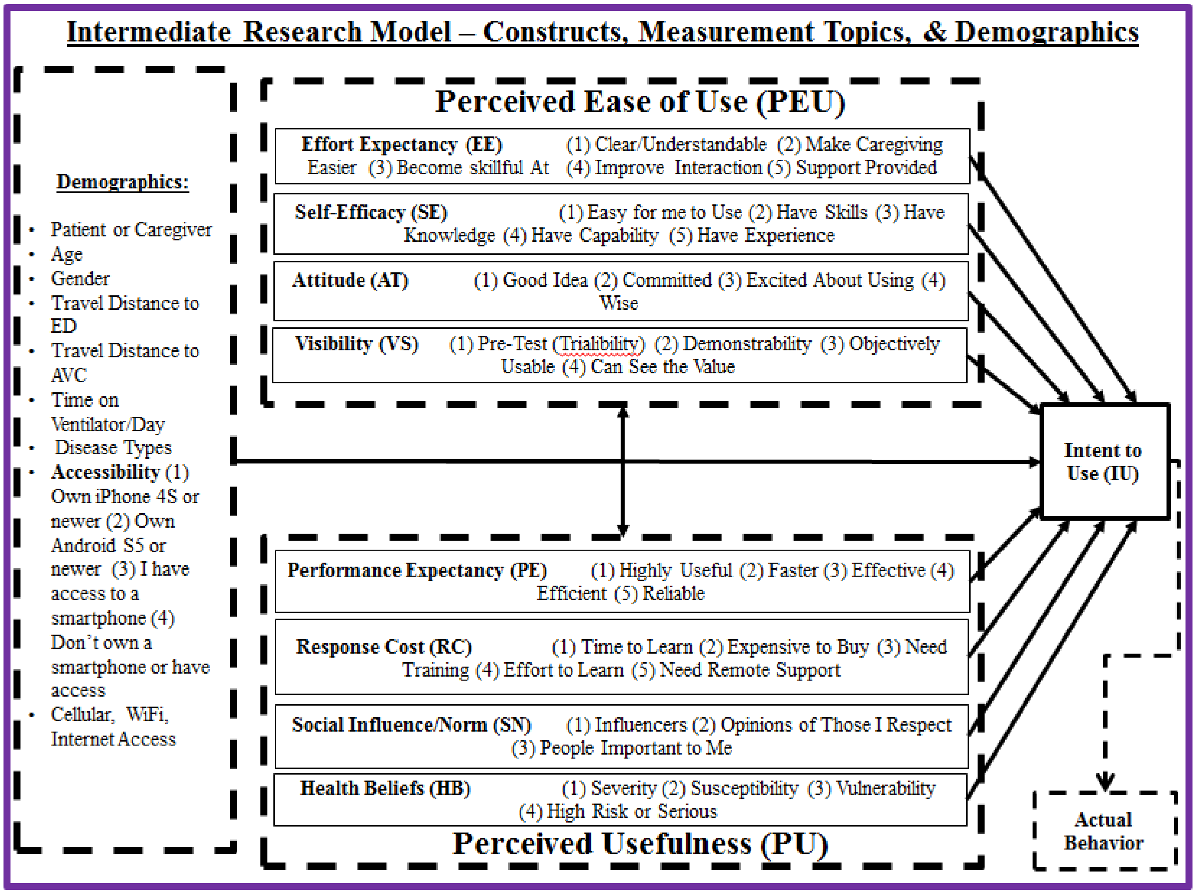


Figure 18. Refined intermediate research model, including constructs, measurement items, and demographics.

The measurement items listed in each construct (e.g., *effort expectancy* or EE: (a) Clear/Understandable, (b) Make Caregiving Easier, (c) Become Skillful At) translate into individual questions. There are 14 demographic questions that combine with 24 additional Likert-type questions yielding a total of 38 questions. The 24, 5-item Likert-type questions (measurement items) are distributed across *perceived usefulness* (12 questions), *perceived ease of use* (11 questions), and *intent to use* (1 question). A completed and final conceptual model including constructs, sub-constructs, measurement items, and demographics create a final conceptual framework as shown in Figure 19.

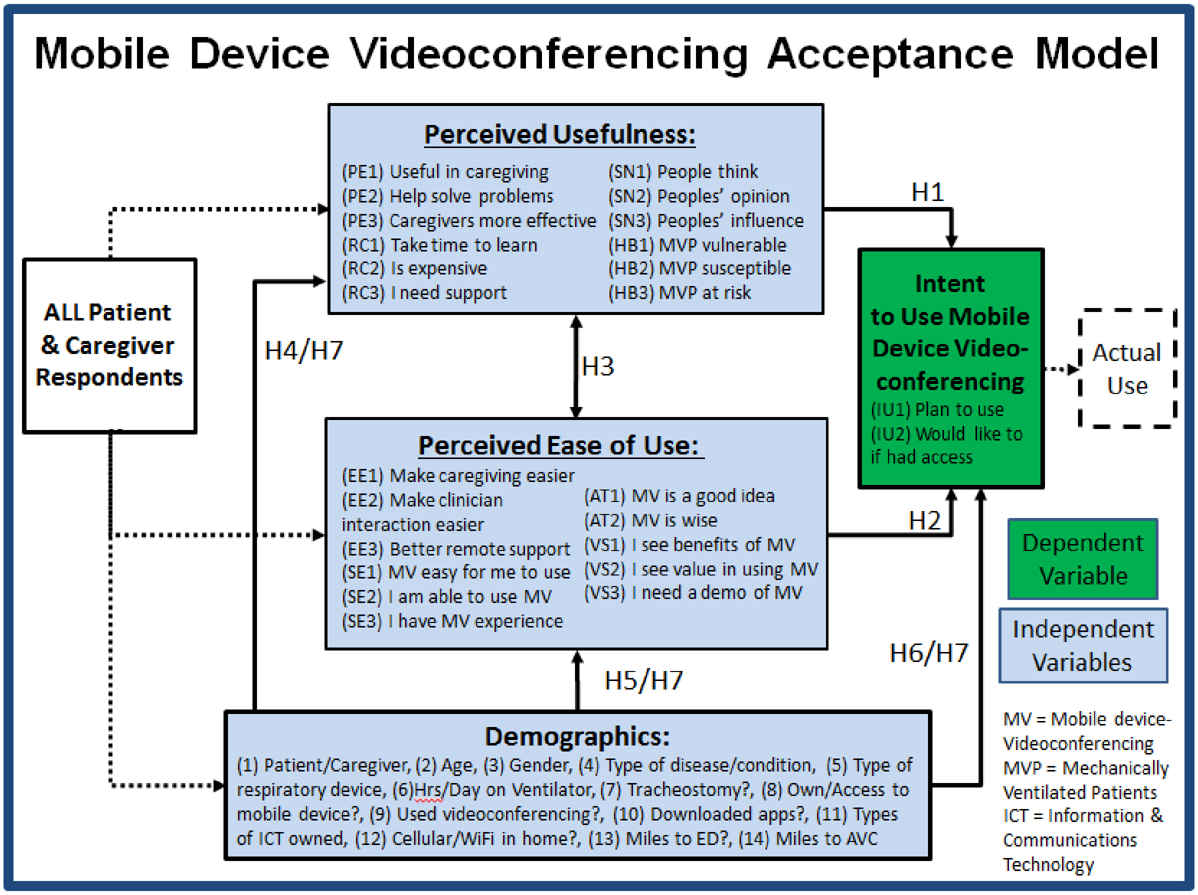


Figure 19. Final research mobile device videoconferencing acceptance model with null hypotheses.

It should be noted that the null hypotheses listed in Chapter 1 are mapped onto the relationship arrows in the Figure 19 conceptual research model. The null hypotheses represent the relationship between *perceived usefulness* and *intent to use*. Likewise, H2 between *perceived ease of use* and *intent to use*, H3 between *perceived usefulness* and *perceived ease of use*, H4 between mobile device *own/access* and *perceived usefulness*, H5 between mobile device *own/access* and *perceived ease of use*, and H6 between mobile device *own/access* and *intent to use*. Finally, H7 represents relationships between the other demographic responses (other than mobile device *own/access*) and the three main constructs (*perceived ease of use*, *perceived usefulness*, and *intent to use*).

The final questionnaire. The Assisted Ventilation Clinic final questionnaire is presented in Appendix E and includes 14 demographic questions and 24 Likert-type questions related to patients and caregivers perceptions. Although the questionnaire focuses on the approximately 670 Assisted Ventilation Clinic patients, based upon the fact that each patient must have two caregivers, the total population of all respondents could be three times the 670 patients or 1620 respondents.

Reliability and validity. Ensuring the reliability and validity of the questionnaire are critical for a successful study. The goals of reliability are constancy, internal consistency, and replicability. Some methods used to examine reliability are (a) test-retest (correlation over time), (b) inter-rater evaluation (correlation between multiple test takers), (c) parallel forms (divide items and test), and (d) internal consistency (appropriate divergence and convergence) to ensure quality measurement (Litwin, 1995). Test-retest is most effective when respondents are making observations—our questionnaire focuses on perceptions, so the test-retest reliability measure was not used. Inter-rater reliability testing was performed during the pilot test based upon six questions related to the pilot questionnaire. The "parallel test" reliability examination was not used—only one questionnaire was created and used for asking questions. Internal consistency reliability was measured by creating a matrix of average inter-item correlations between measurement items and then the average item correlations were summed and averaged and then a total average item total was computed. Cronbach's alpha was generated by computing the average correlation of all split-half correlations (Trochim, 2001).

The concept of reliability can be expressed by the metaphor of shooting at a target. If all your shots at the target are tightly grouped together, it demonstrates high reliability.

However, it may not demonstrate validity—the tight repeatable pattern could be far from the bullseye. If on the other hand, the pattern repeatability is tight and centered on the bullseye, both reliability and validity are demonstrated (Trochim, 2001). Although the measurement items are adapted to remote mechanically-ventilated patient management, the constructs are collected from many studies (such as the key 18 research papers) which have tested the reliability of the constructs over a variety of research settings and the constructs chosen have been proven reliable over time and in different settings.

In addition to questionnaire reliability, validity must also be examined. There are many different types of validity that focus on various aspects of the measurement theory. They include (a) face validity, (b) construct validity, (c) concurrent validity, (d) content validity, (e) criterion related validity (including convergent and discriminant validity), (f) internal validity, and (g) external validity. All these types of validity play a role in examining the translation of theory, concepts, constructs, sub-constructs, and measurement items as they are operationalized in the questionnaire (Litwin, 1995).

In general, validity can be broken down into two groups—construct validity (including face and content validity), which focuses on how well theory and constructs are translated and operationalized, and criterion-related validity (including predictive, concurrent, convergent, and discriminant validity), which focuses on how effectively the questionnaire, in this case, captures the domain of mechanically-ventilated patients and caregivers (Litwin, 1995). Although the questionnaire was constructed from measurement items (questions) from the 18 focus papers (which were also adapted from previously validated research measurement items and constructs), the proven construct validity of this particular questionnaire can really only be measured over time.

Face validity simply estimates how well, on the surface, the questionnaire appears to operationalize the theory, constructs, sub-constructs, measurement items and so on to capture the patient's or caregiver's *intent to use*. To evaluate face validity, an expert panel of people who are familiar with mechanically-ventilated patients, their conditions and care, survey instruments, Assisted Ventilation Clinic operations, other TAM and HBM models and research, and professionals (doctors, nurses, and respiratory therapists) examined the questionnaire, its constructs, and variables. Face validity can also be evaluated by people with no expertise in the subject but can provide a subjective review of how good the questions appear to them. Their feedback included readability, understandability of terms, time taken to complete the questionnaire, unclear or confusing questions, or any other suggestions or comments they may have. Although many of the questions were adapted or rephrased in alternate form from structured from questions taken from the 18 focus papers, which had good reliability and validity, this adapted questionnaire still required a pilot test allowed the collection of some data for reliability and validity measurement.

Content validity focuses on how well the questionnaire captures the domain of remotely mechanically-ventilated patient management. A summary of Assisted Ventilation Clinic mechanically-ventilated patient management criteria and characteristics is presented in Appendix H. Matching constructs and questions to issues related to remote mechanically-ventilated patient management supports strong content validity.

Turning to criterion-related validity, predictive validity is a key reason for this questionnaire and study. Do patients and caregivers own or have access to mobile devices and do they intend to use that technology for remote ventilated patient management? Being able to predict the level of *intent to use* based upon demographic variables, perceptions, beliefs, and other factors are valuable in scaling services to match the patients' and caregivers' *intent to use* mobile devices for remote mechanically-ventilated patient management. Concurrent validity relates to the questionnaire's ability to distinguish between different groups and their predictability—some groups include different age groups, patients versus caregivers, those at greater distances from the Assisted Ventilation Clinic service or the emergency department, those with more complex and serious medical conditions, and a variety of other factors.

Two additional aspects of criterion related validity include convergent and discriminant validity, or how well the measurement items or variables measure what was intended in their implementation. Criterion-related validity focused on the ability of questions or measurement items to differentiate and measure *intent to use* based on the eight sub-constructs and also contained in the two main constructs *perceived ease of use* and *perceived usefulness*. The intra correlations between measurement items were also analyzed. There should be strong correlation between (a) *perceived ease of use*, EE, SE, AT, and VS, and (b) *perceived usefulness*, PE, RC, SN, and HB—this should demonstrate convergent validity between variables measuring similar concepts. Likewise, inter-correlation between items in categories (a) and (b) should be low, which demonstrates discriminant validity among measurement items and constructs that are measuring different things (e.g., ease of use versus usefulness). In summary, within group correlations should be strong while between groups correlations should be weak (Leedy, 2005; Trochim, 2001). These correlations were captured in a correlation matrix and also were analyzed using factor analysis to determine if hidden effects or latent variables not captured in the questionnaire's constructs may be impacting the data and variance. Factor loading also be measured to ensure variables not contributing to the correlation with *intent to use* can be eliminated or verified that they are contributing factors.

Human Subjects

This descriptive questionnaire and research required both the University of Michigan's and Eastern Michigan University's IRB approval (with EMU IRB having final decision as the degree granting institution)—the intent of this study was to produce publishable results and goes beyond clinical quality improvement. Please refer to Appendix I for the IRB approval request sent to Eastern Michigan University and the University of Michigan Institutional Review Boards. In addition to the IRB reviewers, human subject informed consent is ultimately governed by legislation contained in the Code of Federal Regulations, Title 45, Part 46, 2009.

The goal of this questionnaire was to characterize the patients, caregivers, and family who are supported by the Assisted Ventilation Clinic, determine patient and caregiver *intent to use* telemedicine videoconferencing for remote mechanically-ventilated patient management, and test several hypotheses based upon constructs that may correlate with *intent to use*.

Previous research under the umbrella of improving clinical quality of care examined the use of desktop and laptop computers, smartphones, and tablets using videoconferencing in remote care and guidance. Although the preliminary investigation examined the use of desktop and laptop computers with webcams in remote patient management, this study only focused on gathering mobile device videoconferencing data using a questionnaire. Using the preliminary investigation results, a mini-pilot investigation focused on three invasively mechanically-ventilated patients who had an iPhone 4S, an iPad Mini, and an Android smartphone. Positive results were obtained and a basic clinical interactive workflow was created regarding interaction between the clinicians at Michigan Medicine and the patients and caregivers at home. These investigations related to improving the quality of patient care and did not require IRB approval because the results were not published. The next step is to begin actual survey research using a questionnaire which required IRB approval by the University of Michigan and Eastern Michigan University.

An essential part of human subject data collection is obtaining informed consent from patients and caregivers who must voluntarily agree to participate in the study and complete the questionnaire. This informed consent included name of the study; name of the principal investigators; a statement that the study involves research; an explanation of the research and what the participant can expect (e.g., number of questions); an indication of those who are participating, its purpose, possible benefits of the research, risks in participating in the study; how the data was managed (in terms of confidentiality, procedures, storage, and anonymity); indication that the study is totally voluntary; the potential number of participants; average length of time required to complete the questionnaire; a statement that no payment is required; and that there was no penalty for not participating.

Obtaining patient and caregiver informed consent was obtained by using one of the methods outlined in the data collection procedures section that follows. The informed consent information is included at the beginning of the questionnaire. By continuing on to the demographic and Likert-type questions, respondents provided implied consent whether using the paper, online, or telephone/interview versions of the questionnaire. Online options for completing the questionnaire in the clinic included using an Assisted Ventilation Clinic iPad

Air tablet or personal mobile devices accessible by patients and caregivers. Please refer to Appendix G for the Informed Consent Agreement which is part of the final questionnaire.

Data Collection Procedures

Patient consent was required even though patient names and identifying information were not collected. This questionnaire collected population data related to demographics and several constructs that had potential to be related to *intent to use* videoconferencing for remote patient management, mobile device accessibility, patient/caregiver ability to use videoconferencing, and other valuable information.

Originally, the plan was to prepare a video describing telemedicine/ videoconferencing, which could be viewed online. Due to time and resource limitations, pictures in the questionnaire and a short demo using a smartphone were used. The decision was made to have a single common form for the questionnaire regardless of what type of distribution method was used—all participants would see the same basic questionnaire and introductory information.

The survey can be completed using several optional modes in an attempt to reach all approximately 670 Assisted Ventilation Clinic patients and their associated caregivers. The potential methods that survey data can be collected from patients and caregivers were described earlier and include the following:

- Completing a paper version of the questionnaire while waiting in the Assisted Ventilation Clinic to meet with clinicians.
- Completing the questionnaire on an Assisted Ventilation Clinic iPad in the Assisted Ventilation Clinic while waiting in the clinic.

- Completing the questionnaire on their computer at home after receiving a Qualtrics link to the questionnaire in an email.
- Completing the questionnaire on their personal smartphone or tablet after receiving a Qualtrics link to the questionnaire in an email.
- Completing a paper version of the questionnaire at home and returning it to the Assisted Ventilation Clinic in a self-addressed envelope with postage paid.
- Completing, as a final resort, the questionnaire can be completed over the phone by an interviewer asking the patient or caregiver questions over the phone. The drawback to telephone interviewing is the patient/caregiver not being able to see the images at the beginning of the questionnaire which may create some bias.

Overall mobile device ownership and availability for the population in general is valuable for future planning in telemedicine services roll-out.

The questionnaire was created in Qualtrics and data stored in the Qualtrics PHI compliant cloud storage. Data were collected as mentioned above. Questionnaire measurement items were reviewed by Jeanette Brown, MD, PhD; Julie Hanley (nurse practitioner); Armando Kurili (respiratory therapist); Kim Rochefort (nurse); and Brian Smith a telemedicine engineer from the Virtual Health group. In addition, the questionnaire was field tested with pulmonary experts and information technology videoconferencing professionals. The University of Michigan also has several eHealth review committees, and their input would be valuable in constructing a research study that is optimally beneficial to all concerned. The questionnaire data were collected over a period of about two month, each Tuesday and Wednesday of each week.

A pilot test was conducted before the questionnaire was finalized for distribution to the Assisted Ventilation Clinic population. The goals of the pilot test were to (a) ensure the readability of the questionnaire was understandable at an eighth grade level; (b) the terms, processes, and instructions were understandable; (c) estimate the reliability of the questionnaire using the Cronbach alpha test for internal consistency (which must be > 0.70); (d) obtain an average time it took to complete the questionnaire; and (e) provide an open ended question at the end for any additional comments from the pilot testers regarding any lack of clarity or issues they encountered completing the questionnaire. A minimum of 10 pilot respondents were used gather feedback on the integrity of the questionnaire. They were not subject matter experts but were representative of those who actually completed the final questionnaire.

A link to the final Assisted Ventilation Clinic online questionnaire is included as a reference for review (VentQuest, 2017)

Data Analysis

The remote mechanically-ventilated patient/caregiver management questionnaire contains the full spectrum of data types: nominal, categorical, ordinal, interval, and ratio. The initial 14 questions gathering demographic questions contain nominal/categorical data (e.g., disease type, respiratory assist device type, mobile device types), dichotomous data (e.g., sex, yes/no questions), and ratio data (e.g., miles to the emergency department/Assisted Ventilation Clinic, hours/day using ventilator). The decision was made to use a Likert type scale for the 24 questions collecting data related to the constructs *intent to use*, *perceived ease of use*, *perceived usefulness* and all their constructs, sub-constructs, and measurement item question measuring perceptions, beliefs, experience, and attitude. For the past 50 years, there has been controversy in the research community regarding whether Likert scales are ordinal or interval data types. Some argue that Likert scales are ordinal and non-parametric tests must be used—"the average of 'fair' and 'good' is not 'fair-and-a-half'" (Jamieson, 2004). Others argue that computers now allow the use of visual analog scales (VAS; Bishop & Herron, 2015), which provide a continuous scale and create interval data (which allows parametric tests to now be used). One study found that Pearson and Spearman rho tests (parametric vs. non-parametric) yielded the same results (while the Kendall tau result was different than the other two; Murray, 2013). For this study, a 5-point Likert scale was chosen with all points labelled and the combined questionnaire results from the 24 perception questions from the approximately 670 patients and caregivers were treated as interval data—parametric tests were used on the Likert data based upon the strong assurance by Norman (2010) who states, "parametric statistics can be used with Likert data, with small sample sizes, with unequal variances, and with non-normal distributions, with no fear of 'coming to the wrong conclusion'. These findings are consistent with empirical literature dating back nearly 80 years" (p. 631). The intervalist position (versus the ordinalist position) is reinforced by Grace-Martin (2016) who provides recommendations of at least using a 7-point scale, double checking by using non-parametric tests in parallel, and using a more stringent alpha level of significance such as .005 or .01 if possible (values hovering around $p = 0.05$ may be questioned). A 7-point scale added more complexity to the questionnaire, and based upon an eighth grade level, a 5-point scale seemed adequate to treat the data as interval type data assuming 100 or more respondents completed the questionnaire.

Data analysis included descriptive and inferential statistics. Descriptive statistics included: single variable summaries, such as frequency, percentages, mean, median, mode, and range, and standard deviation among others. Inferential analysis included variance and correlation. Examples include how age relates to mobile device ownership or how distance relates to openness to telemedicine as an alternative to travel. Some variables include age, ventilation level, distance from clinic, mobile devices owned, experience downloading and using applications, openness to videoconferencing telemedicine, and satisfaction of care given by the Assisted Ventilation Clinic. The data was also analyzed to determine the average of the population as well as specific patient's *intent to use* mobile device videoconferencing in remote support. Also, a technology profile was created of the overall Assisted Ventilation Clinic population. This profile includes Apple smartphones and tablets, and Android smartphones and tablets that the patients and caregivers either own or have access. Significant relationships may be uncovered by analyzing the data (e.g., the greater the distance from the emergency department or Assisted Ventilation Clinic, the greater the *intent to use* mobile devices in remote patient care). The questionnaire should provide a rich set of data to characterize the mechanically-ventilated population.

The 14 background or demographic questions and 24 Likert questions provided the demographic variables and measurement items in the questionnaire. The demographic variables include patient/caregiver, age, sex (male/female), disease/condition, respiratory device used, hours/day on ventilator, tracheostomy (yes/no), 8:00 a.m.–5:00 p.m. M–F mobile device access (yes/no), used videoconferencing before (yes/no), type of ICT owned or access, cellular/WiFi in patient's home (yes/no), miles to emergency department, and miles to Assisted Ventilation Clinic. In addition to the 14 demographic variables listed above, there are three main constructs: *intent to use*, *perceived ease of use*, and *perceived usefulness,* which comprise the main components of the conceptual model. The construct *perceived ease* *of use* contains four sub-constructs: *effort efficacy*, *self-efficacy, attitude*, and *visibility*. The construct *perceived usefulness* contains four sub-constructs: *performance expectancy, response cost, social influence,* and *health beliefs*. The measurement items for each of the main constructs are captured in 24 Likert-type questions.

Correlation between the main constructs was examined and presented in Table 8 format. The goal was to determine the strength of relationship between *perceived ease of use* and *intent to use, perceived usefulness* and *intent to use*, and *perceived ease of use* and *intent to use*. The range of correlation coefficients lie between -1 and +1, a strong negative correlation is indicated by an *r* value near -1 or a strong positive correlation indicated by an *r* value near +1, while a value near 0 indicates no correlation.

Table 8

Construct Mean, Standard Deviation, and Correlation Matrix

Construct	**Mean**	**Standard Deviation**	***Intent to Use***	***Perceived Ease of Use***	***Perceived Usefulness***
Intent to Use (I2U)	Mean	Standard Deviation	-	-	-
Perceived Ease of Use (PEU)	Mean	Standard Deviation	PEU/I2U Correlation	-	-
Perceived Usefulness (PU)	Mean	Standard Deviation	PU/I2U Correlation	PEU/PU Correlation	-

In addition to discovering any strong correlative associations or relationships between constructs, it was valuable to determine the level of significance of that correlation. The level of significance for the correlation measure is $\alpha = 0.05$. Knowing the *r* correlation coefficient, the degrees of freedom, the level of significance (α), and whether it is a two- or one-tailed test, it is possible to determine whether the level of correlation is significant or not. Discovering this result allowed rejection or acceptance of the null hypotheses.

A table containing the means and standard deviation of the constructs and sub-constructs was created and was also included the number of measurement items associated with each construct or sub-construct along with the Cronbach alpha for each construct and sub-construct. Values above 0.7 indicated the reliability of the questionnaire construct components.

Also an ANOVA was performed and results presented in Table 9 format.

Table 9

Multivariate ANOVA Table for Mechanically-ventilated *Patient Management Using all Independent Variables and Covariates*

Independent Variable	Sum of Squares	Df	Mean Square	F ratio	p value
Variable 1	x.xx	n-k-1	x.xx	x.xx	0.xxx
Variable 2	x.xx	n-k-1	x.xx	x.xx	0.xxx
Variable 3	x.xx	n-k-1	x.xx	x.xx	0.xxx
Variable n	x.xx	n-k-1	x.xx	x.xx	0.xxx

Note: *p < .05. **p < .01 ***p < .001 Author can provide additional information here.

Finally, hypothesis testing was performed on all the variables and factors. Due to the different types of variable data types, different tests were performed on the data to determine correlation and levels of significance. Table 10 lists the hypotheses, the variable data types, and the statistical tests that were performed to determine the degree of correlation and the levels of significance. The correlation coefficient was captured in the *r* value which ranges from -1 (strongly negative correlation), to 0 (no correlation, to +1 (strongly positive correlation). When measuring levels of significance against an α of 0.05, anything measuring less than 0.05 indicates a rejection of the null hypotheses and evidence for the alternative hypotheses.

Table 10

Null Hypotheses, Data Types, Variables, and Associated Statistical Tests

Null Hypoth-eses	**Independent Variable**	**Type**	**Second Variable**	**Type**	**Test**
$H1_0$	*Perceived Usefulness*	Ordinal (Interval)	*Intent to Use*	Ordinal (Interval)	Pearson Product-Moment Correlation Coefficient (compare to Spearman Rho)
$H2_0$	*Perceived Ease of Use*		*Intent to Use*		
$H3_0$	*Perceived Usefulness*		*Perceived Ease of Use*		
$H4_0$	*Own/Access* to Mobile Devices (only)	Nominal/ Dichotomous	*Perceived Usefulness*		Independent t-Test; Point Biserial Test
$H5_0$			*Perceived Ease of Use*		
$H6_0$			*Intent to Use*		
$H7_0$	- Age? - Miles to emergency department? Assisted Ventilation Clinic? - # of hrs/day on ventilator?	Interval/Ratio	*Intent to Use*		Pearson Product-Moment Correlation;
$H7_0$	-Patient/Caregivers -Disease type? -Type of respiratory assist device? -Mobile devices own or have access?	Nominal/ Categorical	*Intent to Use*		Kendall tau
$H7_0$	-Sex? -Tracheostomy? -Used videoconferencing before? -Downloaded an app? -Access to mobile device 8am-5pm/M-F? -Cellular/WiFi access @home? -Used videoconferencing? -Downloaded an app?	Nominal, Dichotomous	*Intent to Use*		ANOVA, Point Biserial

$\alpha = 0.05$; r range -1 to +1

The path diagram in Figure 20 depicts the hypotheses connecting the major constructs in the study. Correlations were performed on $H1_0$–$H7_0$ and levels of significance tests were performed to determine if the null hypotheses stating there are no significant levels of relationship between major constructs exists or if the alternate hypotheses are true.

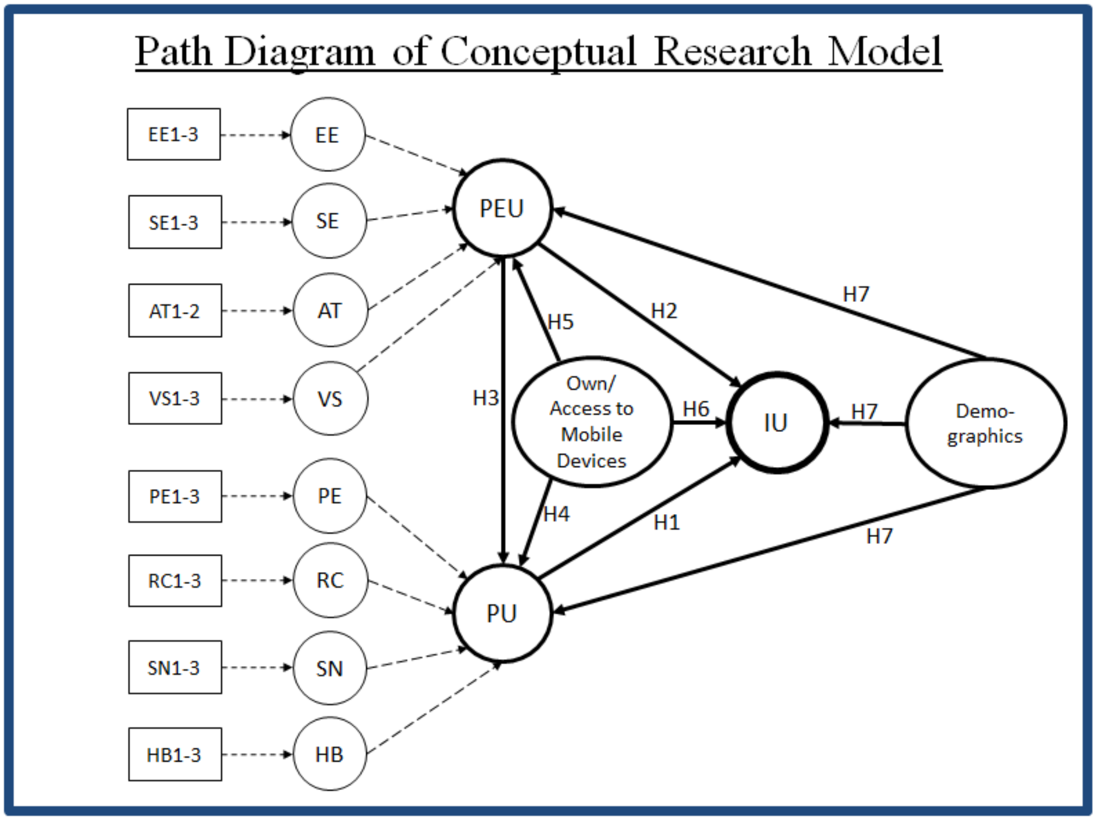


Figure 20. Path diagram of conceptual research model.

Regression analysis was not performed on the dependent variable, *intent to use*, and the other independent variables *perceived usefulness*, *perceived ease of use*, and *own/access to mobile devices* to uncover any inferential relationships. Also, exploratory factor analysis was performed on the data collected from the 24 Likert-type questions to examine loading, correlation contribution, and reliability.

Chapter 4: Data Analysis and Results

Introduction

The primary focus of the data analysis was to determine patient's and caregiver's *intent to use* mobile devices in remote patient care. Data collected in the Michigan Medicine adult Assisted Ventilation Clinic from early November 2016 through early February 2017 provided input to the analysis process. Whether the analysis involved one of the 14 demographic variables, the 24 Likert-type variables, exploratory factor analysis, hypotheses testing, or reliability testing, it all revolved around determining if there was a significant correlation or relationship between the variable and *intent to use*.

Statistical analysis was performed using SPSS Version 24. The analysis provided a better understanding of this unique Assisted Ventilation Clinic population and provided insight into differentiating which types of patients and caregivers perceive telemedicine positively and which are opposed to using the technology. The data allowed for the characterization of the population and for an understanding of the extent of information and communication technology owned by patients and caregivers—this technology is essential as it provides the infrastructure to implement telemedicine. The two key questions answered by this study are (a) "if telemedicine capabilities are implemented, do patients and caregivers intend to use this technology?" and (b) "is there a patient and caregiver owned mobile device infrastructure, connectivity, and experience to support telemedicine services?"

This chapter is organized around the chronological roll out of the questionnaire from creation to final data collection and analysis. The *Level of participation* section describes both those willing to complete the questionnaire and those who refused or were unable to participate at all. Capturing data about both respondents and non-respondents was important in gaining an unbiased and complete picture of the Assisted Ventilation Clinic population. The *Data Analysis* section provides the raw statistical properties of the independent or control variables creating the framework in which to examine respondents' opinions. An analysis of the Likert-type questions includes normality testing to guide the selection of statistical tests. Once normality has been confirmed (or data transformations have been performed to satisfy normality requirements), the reliability of the question items were can be analyzed using Cronbach's alpha. Finally, hypothesis testing was performed using inferential statistics to determine if significant relationships exist between variables.

Final Instrument Design

Finalizing the instrument utilized expert panel input, pilot testing (which involved the completion of Likert-type questions regarding the questionnaire per se), and the researcher noting any parts of the questionnaire the respondents had difficulty completing. Pilot test results and observations were analyzed and the results were used to modify the final instrument and the delivery systems to potential respondents. A patient education expert was also consulted regarding questionnaire understandability.

Expert panel input. The expert panel was comprised of experts in telemedicine, physical medicine and rehabilitation, rehabilitation engineering research, patient education, the Assisted Ventilation Clinic, and dissertation committee members. They reviewed the pilot questionnaire which contained all the elements of the final questionnaire in addition to separate pilot study questions. Feedback included simplifying the wording, reducing the busyness and clutter, reworking confusing wording, using the readability statistics (contained in Microsoft Word) to identify words that elevated the reading level above eighth grade, input from a patient education expert, and advice on using patient first language. An example of patient first language is using “people who use ventilators” instead of “ventilated patients”—the focus is on people first, with other modifiers following. A standard informed consent template was used to construct the informed consent document. Originally, this template alone had a reading complexity of a fourth-year college level (grade 16) and required extensive simplification but still remained above eighth grade level even with modifications. The proposed final questionnaire was reduced to a single sheet of paper using both the front and back.

Additional guidance from the panel included simplifying the language, reducing the *busyness*, eliminating unnecessary typed words (e.g., repeating Likert agree or disagree anchors for each question), formatting improvements, and phrasing improvements. There was a suggestion to replace the words vulnerable and susceptible (personal perception words) with the quantitative terms often or frequently. Vulnerable and susceptible were retained to capture respondent perception—few or many events did not necessarily capture the anxiety the respondent may experience from those types of events. A final suggestion was made to have separate questionnaires for patients and caregivers to eliminate any confusion about to whom the question was referring, the patient or caregiver. However, the decision was made to proceed with a single questionnaire for both patients and caregivers.

Pilot test results. Pilot test participants were selected from patients and accompanying caregivers in the Assisted Ventilation Clinic for scheduled office visits on Tuesdays and Wednesdays. Each patient (and caregivers) visit the clinic at least once a year. A convenience sample was used to gather pilot data—if they were in the clinic, they were potential respondents and asked to complete the questionnaire.

The pilot test instrument included the final questionnaire's 14 demographic questions and 24 Likert-type opinion questions, plus an additional six pilot test only Likert-type questions to gather feedback on the overall quality of the questionnaire and time needed to complete it. Twenty-six people that represented a random cross section similar to those would be completing the final questionnaire were asked to complete the pilot questionnaire. Of 26 people asked to complete the questionnaire, 20 agreed to and six declined. One of the completed questionnaires was eliminated due to the respondent answering "1 (*Strongly Disagree*)" to all questions. The results of the six questionnaire quality questions are shown in Table 11. It took an average of 6.84 minutes (Table 11) to complete the questionnaire. Pilot test participants indicated that it was not too long, there were not too many questions, it was easy to understand, the questions were not confusing or unclear, and the words used were understandable. Pilot test respondents completed the demographic and Likert-type opinion questions without any issues (refer to Appendix J for the Pilot Questionnaire).

The means and standard deviations seemed reasonable for these Likert-type opinion questions, Q1 to Q24. The mean for the question *intent to use* (Q24) was 3.42 using only the data from those completing the questionnaire. A trend appeared to be developing where those with mobile devices were willing to complete the questionnaire and those who did not own mobile devices were unwilling to complete the questionnaire. The concern was that if only mobile device owners complete the questionnaire, those without mobile device access might be underrepresented in the data collected. As a result, attempts were made during actual data collection to gather data from non-responders (e.g., Did they own a mobile device? Did they think using mobile devices in remote care was a good idea?). This concern was unfounded based on data collected from the 153 respondents.

Table 11

Pilot Test Questionnaire Results

Questions/Time	Mean*	SD
1. The time to complete the questionnaire is too long	1.71	0.77
2. There are too many questions	1.82	0.88
3. The questions are easy to understand	3.94	1.06
4. The questionnaire questions are confusing	1.88	0.99
5. The questionnaire directions are not clear	2.18	1.13
6. The words used are understandable	3.88	1.36
Time to Complete the Questionnaire	6.84 minutes	2.91

Note: * 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree

Although the pilot test questionnaire was intended to be a self-explanatory document (with pictures and text describing mobile device videoconferencing in mechanical ventilation patient management) additional explanation was needed for most people to understand the concept. After several questionnaires were completed, it became apparent that a short elevator presentation was necessary to introduce the questionnaire. Initial questions for the patients and caregivers included asking up front if they had mobile devices, had ever used Skype or Facetime, or were familiar with telemedicine. The six pictures on the cover sheet provided visual examples of how mobile devices could be used. A mobile device was used in picture mode to provide an example of face-to-face videoconferencing where they could see themselves using the front camera—"this is how it looks when talking with a clinician." Then the display was switched to the back camera which was pointed at a hand while verbal guidance was given to touch the thumb to the little finger while observing what a remote expert would observe. This explanation seemed to bring all potential respondents to the same level of understanding. At this point they were asked if they would like to participate in completing the questionnaire.

Pilot test impact. In the paper version of the pilot questionnaire, respondents wrote additional information about their diagnoses (Q4), respiratory equipment (Q5), and general comments at the end. To accommodate additional input or clarification respondents wanted to make, text boxes were added to the on-line version to accept text data entry. Also, Apple Smartphone and Apple Tablet were changed to Apple iPhone and Apple iPad, and the on-line versions of the questionnaire were updated to match the paper version. Once these changes were made the instrumentation was ready for data collection.

Data Collection

Attempts were made to have multiple data collection options. However, ultimately, the researcher collected data face-to-face and provided a short explanation of using mobile devices for remote care, a short mobile device demo, and remaining with the respondents while they completed the questionnaire using either the paper version or on-line version. The paper version had the advantage allowing an immediate check to make sure all questions were answered and returning it if incomplete. Respondents wanting to complete the questionnaire on-line were provided an iPad or used their mobile device and a shortened URL link (Bitly, 2016) connecting them to the Qualtrics questionnaire. Respondents could use their own mobile devices and the Bitly (2016) link or a QR (Quick-response) Code link to connect to the questionnaire (see Figure 21).

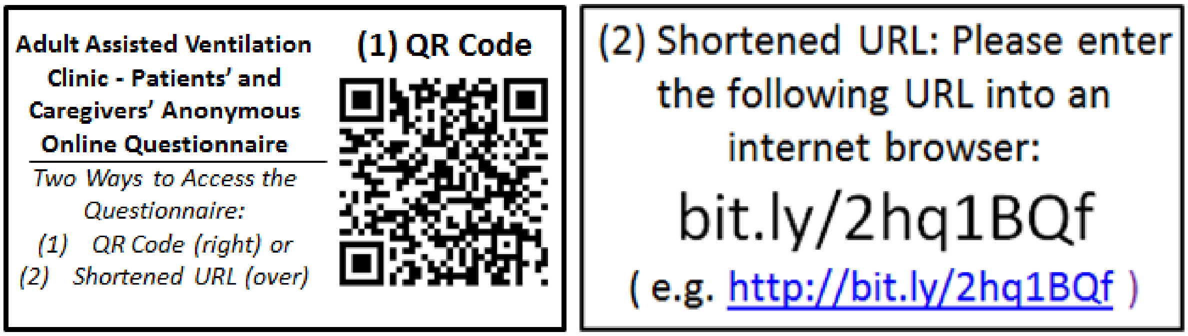


Figure 21. Business card with QR code and shortened URL links. The QR code on the front allowed participants to scan the link into their mobile device for completion. The shortened bit.ly address on the back allowed the questionnaire link to be entered in a web browser.

Three additional collection methods were investigated (a) using the patient portal, (b) using the Health Research (2016) website, and (c) by phone. In October 2016, compliance and the research council were asked if the *MiChart Patient Portal* could be used to provide a Qualtrics link to the questionnaire in its questionnaire tab. The IRB also expressed interest in whether the patient portal could be used. In January 2017, the decision was received that the patient portal could not be used for research. Approval was given to put a link to the questionnaire on the Health Research (2016) website, which would have provided access to 26,000 people that accessed the website to investigate potential research participation. The decision was made not to use Health Research (2016) because this would intersperse non-Assisted Ventilation Clinic patients and caregivers into the Assisted Ventilation Clinic population. Phone access was approved but not used due to difficulty in explaining telemedicine concepts. Ultimately, the researcher used the paper and online methods along with a discussion using the six questionnaire pictures and a short demo using a smartphone. Other methods didn't allow a consistent message to the potential respondents.

Respondents. Potential respondents included the total patient population supported by the Assisted Ventilation Clinic or approximately 670. Each patient is required to have two caregivers, resulting in at least 1,340 caregivers in the system—some patients have more caregivers while others have fewer caregivers because their disease or condition is in the early stages and is not as severe. Thus, a total of 1,620 people could potentially be questioned each year. Collection began on December 21, 2016 and ended on February 1, 2017, or seven weeks. Data collection occurred during clinic visit days, Tuesdays and Wednesdays each week. A total of 1,620 potential respondents visit the clinic each year, approximately 31 per week. Over a seven week period, approximately 217 patients pass through the clinic. Due holidays and severe weather, some collection days were below average resulting in the 188 people asked. Due to the way patients were processed in the clinic, some patients passed through the clinic and left without being asked to complete the questionnaire and were not included in the 188 total.

On collection days, patients come to the clinic and are escorted to a room. Clinicians rotate into the patient's room based upon both the clinician and patient being available. A white board tracks clinicians across the top row while patients, their room number, and arrival time are entered in the left column—this creates a matrix for entering times clinicians go into a room. Clinicians include PM&R/neurology/pulmonary physicians, social workers, dietitians, a pulmonary nurse practitioner, and a respiratory therapist. If matrix cell formed by the clinician and the patient is empty, the clinician puts the current time in the cell and visits the patient. When they are finished with their visit, they *X* out the time in the cell. This frees up the patient to see other clinicians as they are available. The person collecting data was allowed into this clinical rotation.

Lessons learned from data collection. Data collection occurred in person by the researcher to clarify or answer any questions which arose. All patients and caregivers were important to the study, including those that declined to complete the questionnaire. Some patients were unable mentally and physically to complete the questionnaire and/or even answer questions. In some cases, data collection from the patients was impossible because multiple caregivers were performing life maintaining procedures on the patient—it was similar to trying to collect data in an intensive care unit (ICU). Using the paper version allowed the researcher to point out any questions that were overlooked and immediately ask the respondent to fully complete the questionnaire.

Attempting to collect data from the patients and caregivers using a single questionnaire was occasionally confusing to respondents. Adding text boxes allowed data entry of multiple diagnoses and respiratory device types, which caused *Other* to become a major category by itself, making data analysis more difficult. By using *smartphone* in many of the questions, it limited respondents' answers—the term *mobile devices* would have been more inclusive of acceptable technologies that could be used in remote care. Several questions would have benefited from a not applicable (N/A) option. The Likert questions were grouped by sub-constructs and random ordering would have allowed better independent answering of the questions. The question about whether using mobile devices being *expensive* (Q16) created some uncertainty—the cost is very low if mobile devices and connectivity are present in the patient's home but could be very expensive if the technology must be purchased. The demographic portion of the questionnaire was completed without questions or confusion. A few Likert social norm questions were confusing to them about whether *people important to them* (Q18), *people whose opinions they respect* (Q19), and *people who influence them* (Q20) think they should use mobile devices for remote care. This was the first time many of them had heard of this approach to care, and being a new concept, they were unsure how others close to them would advise them. Three other questions some respondents found difficult to answer involved mechanically-ventilated patients being *vulnerable to equipment failures* (Q21), *susceptible to medical emergencies* (Q22), and *at risk of serious issues requiring immediate medical attention* (Q23). These patients were in the early stages of disease progression with limited use of a ventilator and didn't consider themselves using a ventilator. In these cases, I suggested that if they were unsure and couldn't decide definitively to select 3 (*Neutral*).

Some people didn't consider BiPAPs and CPAPs to be ventilators, which resulted in Q21–Q23 being confusing. The format of the *intent to use* (Q24 a and b) was confusing to some and they ended up answering both parts of the question—the first part (Q24a) stated "I own or have access to mobile devices…" while the second part (Q24b) stated "I do not own or have access to mobile devices, but if I did…"

Completed questionnaires don't necessarily represent the whole population. If patients strongly insist on not completing the questionnaire, the negative respondents may be more biased toward not using mobile device videoconferencing. The attempt was made to track all people in some way, even if they didn't complete the questionnaire.

Response rate. A total of 188 people were asked to complete the questionnaire—153 completed the questionnaire while 35 people declined to complete it for various reasons, yielding a response rate of 81%. As previously mentioned, as much information as possible was collected from non-participants which resulted in 35 partially completed questionnaires with no Likert-opinion questions answered. Although limited, some of their data and comments were collected to gain insight into reasons for their non-participation. These non-respondents are discussed in more detail later.

Data Analysis

This section includes a descriptive analysis of the collected data followed by the appropriate inferential analyses. The descriptive results include: demographic statistics frequency, percent, measures of central tendency and variability; Likert-type questionnaire statistics of central tendency and variability, skewness and kurtosis measures; reliability statistics; and qualitative data on the 35 non-respondent patients and caregivers.

Demographic or control variables. There were 14 demographic variables, also called control or exogenous variables. These variables do not vary but represent real world independent variables or facts and are not dependent upon other variables. The demographic variables capture the characteristics and environment of the patients, family or friend caregivers, and professional caregivers—they are the respondents. Answers to these questions are very important to the implementation of telemedicine because operations rely on the infrastructure created by the mobile devices owned or accessible, WiFi or Internet accessibility in the patient's home, and *intent to use* the service.

Measures of interest for categorical or nominal variables are frequency and percent. For interval and ratio variables, mean, standard deviation, range, and minimum/maximum are of most interest. Frequency and percent of these variables are of interest. There are three main groups of respondents, patients, family or friend caregivers, and professional caregivers. They were listed separately so differences in their measures were more obvious.

Table 12 contains the variables age and sex for these three groups. The respondent data collected (including age and sex) indicated there are approximately three times as many family and friend caregivers as there are professional caregivers. The age of family and friend caregivers ranged from 16 (two years lower than the minimum patient age admitted to the Assisted Ventilation Clinic) up to 75 years. The family or friend caregiver age range was greater than that of the patients. Among all caregivers, more females than males were in the role of caregiver and this was especially notable among professional caregivers.

Of the 153 respondents, 73 are patients, 58 are family and friend caregivers, and 22 are professional caregivers. Although each patient is required to have at least two caregivers, not both caregivers joined the patient on their clinical visit. The data collected indicated the patient to caregiver ratio is around 1:1. The average of patients and caregivers is around 50 with professional caregivers on average being younger at an average age of 36. Although patients served by the Assisted Ventilation Clinic must be at least 18 years of age, there were caregivers as young as 16. The sex of patients is equal between males and females. However, more females are caregivers than males for both family/friend and professional caregivers at a ratio of 2.4:1 and 10:1, respectively.

Table 12

Q1–Q3 Demographic Descriptive Statistics Patients, Caregivers, Age, and Sex

Variable	Measure	Patients	Family or Friend Caregiver	Professional Caregiver	Total
1) Respondent	Frequency	73	58	22	153
	Percent	47.7%	37.9%	14.4%	100%
2) Age	Mean	49.22	50.10	36.18	47.97
	Median	50.00	53.5	36	50.00
	Std. Dev.	15.49	15.81	14.58	15.76
	Range	55	59	42	61
	Min/Max	21/77	16/75	19/61	16/77
3) Sex	Male Frequency (%)	35 (23%)	17 (11%)	2 (1%)	54 (35%)
	Female Frequency (%)	38 (25%)	41 (27%)	20 (13%)	99 (65%)

A comparison of respondent age versus their *intent to use* mobile devices in remote mechanically-ventilated management revealed yielded similar levels of agreement from the twenties through the sixties. Likert responses were divided into decade age groups (e.g., 20–29, 30–39) and compared with their individual responses of *intent to use* (Q24), which were grouped into agree, neutral, and disagree (5 or 4 = agree, 3 = neutral, and 2 or 1 = disagree). Results shown in Figure 22 indicate those in their 50s and 60s agree more than those in their 20s, 30s, and 40s to use mobile devices for remote care. Those in their seventies had less agreement on *intent to use* and showed greatest neutrality among all decade groups. Responses indicate that many older people are at least as likely as younger people to use mobile devices in remote patient management in terms of *intent to use.* However, this is not the same as ability to use those mobile devices in remote care, only *intent to use.*

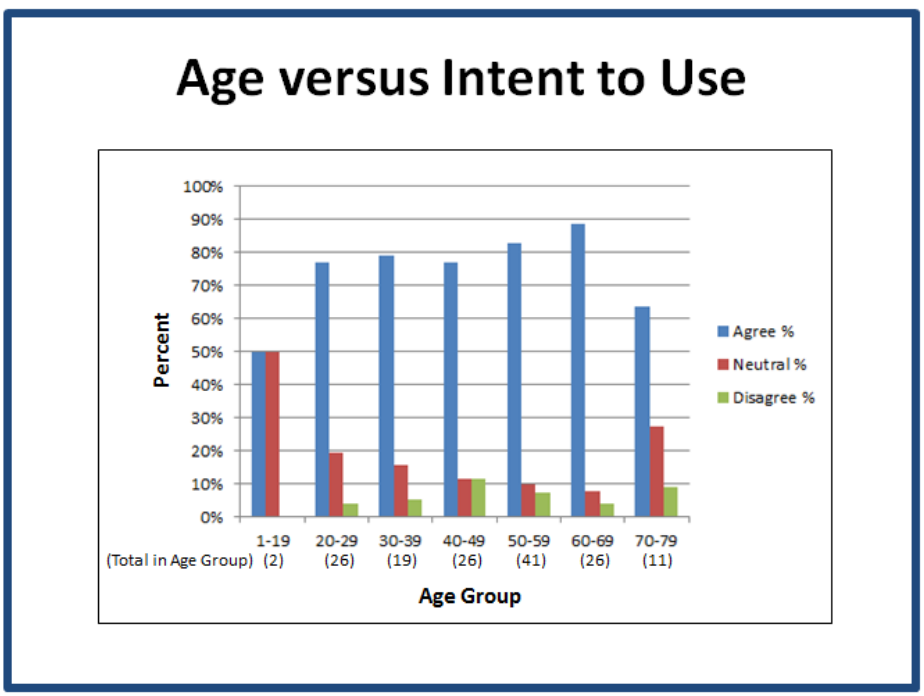


Figure 22. Age versus *intent to use* mobile devices for remote care.

The diagnosis and types of respiratory devices used are listed in Tables 13 and 14. Table 13 lists the diagnoses from the most common, *Other* (being a catch-all category), to the least common, Duchenne muscular dystrophy (DMD). Muscular Dystrophy was the most common diagnosis, followed by spinal cord injuries. An indication of the complexity of care is reflected by the category *Other*, at 32.8%, which reflects the broad range of neuromuscular diseases caregivers and clinicians must be prepared to treat.

Among the respondents, the majority have muscular dystrophy and spinal cord injuries. In addition to ALS, CP, myopathy, DMD and OSA on the questionnaire, the *Other* category (32.8%) included 36 other diagnoses (e.g., AGS, anoxic brain injury, brain stem herniation, CCHS, CHF, COPD, CHV, CMT, CRF, diaphragmatic paralysis, DMZ, Guillain-Barre, PLS/HSP, multisystem atrophy, multiple sclerosis, sarcoidosis, myasthenia gravis, myotonic dystrophy, POMPE, pulmonary constriction, ROHHAD central hypoventilation, SMA Type 1, and traumatic brain injury) demonstrate care complexity.

Table 13

Demographic Question 4—Diagnosis Frequency and Percent

Diagnosis	**Frequency**	**Percent of Sample**
Other	50	32.8%
Muscular Dystrophy	37	24.2%
Spinal Cord Injury	33	21.6%
Amyotrophic Lateral Sclerosis	14	9.2%
Cerebral Palsy	10	6.2%
Myopathy	7	4.6%
Obstructive Sleep Apnea	1	0.7%
Duchenne Muscular Dystrophy	1	0.7%

The frequency and percent of different types of respiratory devices selected are listed in Table 14. The most common combination is the Trilogy ventilator and cough assist device, followed by BiPAP and CPAP. The category *Other* also listed a variety of text entered respiratory devices patients use which is also a reflection of the broad range of knowledge clinicians and caregivers must possess in caring for such a diverse patient population.

The Trilogy ventilator is the most common among the Assisted Ventilation Clinic patients followed by BiPAP, CPAP, and LTV ventilators. The Astral ventilator is the latest model used by the clinic. Along with ventilators, many patients also use a cough assist device. The complexity of care is also exemplified by the variety of respiratory devices used. The *Other* category includes devices such as the A-PAP, the AVPS, the Sip & Puff, the suction machine, and a vibrating chest vest device.

Table 14

Demographic Question 5—Respiratory Device Types: Frequency and Percent

Respiratory Assist Devices	Frequency	Percent of Sample
Trilogy Ventilator	57	27.01%
Cough Assist Device	57	27.01%
Bi-level Positive Airway Pressure (BiPAP)	34	16.11%
Continuous positive airway pressure (CPAP)	24	11.37%
Other	20	9.48%
LTV Ventilator	13	6.16%
Astral	4	1.90%
None	2	0.95%

The number of hours per day that the patients were on ventilators ranged from 0 hours per day to 24 hours per day as shown in Figure 23. There are three spikes in the hours of respiratory device usage. The first is from 0 to 1 hours—patients may have ventilators but using them very infrequently at the initial stages of disease manifestation. The second spike occurs between 6 and 12 hours of use per day. The majority in this category use their devices at night to help with breathing during sleep. There is a clear spike at 24 hours with the largest frequency of usage at 35. This spike represents those patients that must be on respiratory assist devices continuously. Hours on the ventilator peaks around 8 hours due to many who use ventilators mainly during sleeping and peaks again 24 hours for those on a ventilator full time. Most of those on ventilators full time have a tracheostomy—33.3% of the patients have tracheostomies.

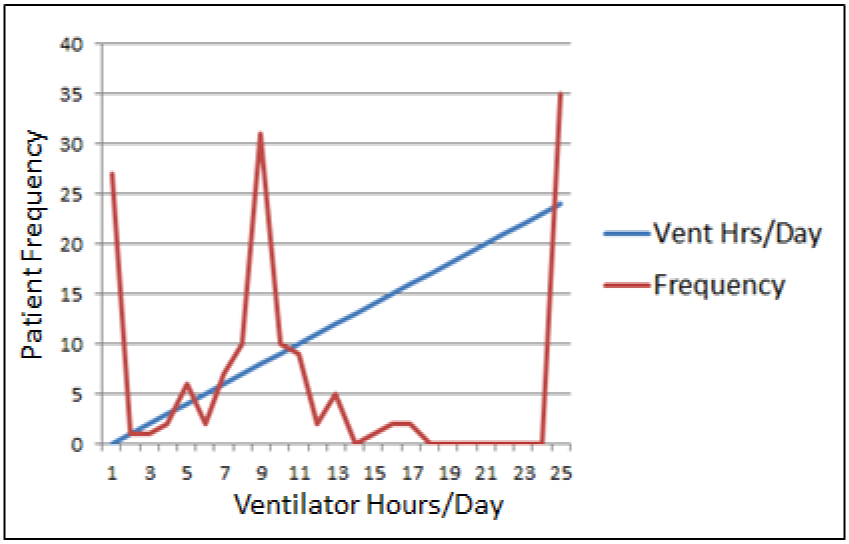


Figure 23. Frequency of patient ventilator use in hours per day from question 6. The three spikes are associated with new ventilator users (1 hrs./day), ventilators used during sleeping (9 hrs./day), and continuous ventilator users (24 hrs./day).

Questions Q7 through Q12 were dichotomous demographic questions with yes/no answers. They inquired about "the presence of patient tracheostomy or not" (Q7), "mobile device ownership or access or not" (Q8), "videoconferencing experience (e.g., Skype or Facetime) or not" (Q9), "experience downloading applications on mobile devices or not" (Q10), and "cellular, WiFi, or Internet access in the patient's home or not" (Q12). Frequency and percent results are listed in Table 15. In a third of the responses, the patient had a tracheostomy. Mobile device ownership or access to one was at 90.8%—this is an infrastructure related question indicating that mobile devices are highly available for use. Not just ownership or access is important for remote ventilated patient management, but experience could also be a large factor related to *intent to use* to be discussed during hypotheses testing. Roughly 75% of the respondents had experience using videoconferencing and downloading applications. Another critical element in the patient and caregiver provided infrastructure is cellular, WiFi, or Internet access. Connectivity from the patient's home already exists in 96.1% of the respondents' environments. This is extremely significant and is higher than mobile device ownership or access due to the impact of connectivity available for laptops and desktops (even though they may not have mobile devices).

Table 15

Demographic Dichotomous Questions Q7, Q8, Q9, Q10, and Q12

Variable	**Yes Frequency (Percent)**	**No Frequency (Percent)**
Tracheostomy? (Q7)	51 (33.3%)	102 (66.7%)
Own/Access to Smartphone? (Q8)	139 (90.8%)	14 (9.2%)
Videoconferencing Before? (Q9)	104 (68.0%)	49 (32.0%)
Down Load App Before? (Q10)	118 (77.1%)	35 (22.9%)
Cellular/WiFi/Internet Access? (Q12)	147 (96.1%)	6 (3.9%)

Demographic Q8 asked if the respondent owned/had access to mobile devices. Q11 goes beyond Q8 in asking an indication of what specific types of information and communication technology (ICT) respondents own or have access. Thus, Q11 provided more detailed data on the patient/caregiver mobile device infrastructure by taking an inventory of all ICT devices owned or accessible by the respondent. This included iPhones, iPads, Android smartphones and tablets, other smartphones and tablets, laptops, and desktop computers. The results were divided a couple ways. First, results were broken down by the types of devices with laptop availability highest, followed by iPhones, then Android phones. More iPads were available for use than Android tablets.

In addition to device types owned, the data also revealed multiple device ownership. Among the 153 completing the questionnaire, only two respondents didn't own any ICT devices, while at the other extreme, four respondents owned five devices (refer to Table 16).

Device ownership peaked at two devices with three devices a close second. Clearly, the respondents have ICT and connectivity available remote ventilated patient management.

Table 16

Question 11—Types and Quantity of ICT Owned/Accessible by Assisted Ventilation Clinic *Sample Population*

Types and Frequency of Information and Communication Technology Owned or Accessible						
Apple iPhone	Apple iPad	Android Phone	Android Tablet	Other Smartphone/ Tablet	Laptop	Desktop
71	53	63	32	25	83	50

Number of Respondents Owning Multiple Devices (Total = 153 People)						
Quantity of Devices Owned	No ICT Devices Owned	1 Device	2 Devices	3 Devices	4 Devices	5 Devices
Number of People Who *Own/Access* X Devices	2	30	50	41	26	4

Another set of demographic variables were tracked that had a potential impact on *intent to use* mobile devices for remote patient management, miles from the patient's home to the emergency department and to the Assisted Ventilation Clinic (Table 17). An analysis follows later but the hypothesis was that distance to receive care might have a motivating impact on *intent to use* (e.g., the greater the distance, the greater the *intent to use* mobile devices remotely).

Questions 8 through 12 focus on mobile device ownership or access, experience, and network access. Approximately 90% of the respondents have a mobile device. Many have already used videoconferencing (68%) and have downloaded applications (77%). Question 11 provided a detailed inquiry of the types and numbers of ICT. The iPhone was the most popular mobile device owned followed by Android phones—similarly, Apple tablets were more popular than Android tablets. Multiple device ownership was very common. Only two respondents had no ICT at all, while laptops were most common type of device owned. Videoconferencing requires network access and 96% of the respondents had cellular, WiFi, or Internet access in the patients home. The existence of all of this technology indicates the existence of a powerful infrastructure for implementing telemedicine.

Questions 13 and 14 were intended to measure the distance that must be traveled from the patient's home to the nearest emergency department and also to the Assisted Ventilation Clinic (refer to Table 17). The assumption behind questions Q13 and Q14 was the hypothesis that the greater the distance for patients and caregivers to travel, the greater the *intent to use* mobile devices for remote ventilated patient management. The average distance to the nearest emergency department is 10 miles (with a minimum of 1 mile and maximum of 60). The average distance to the Assisted Ventilation Clinic is 58 miles (with a minimum of 0 miles and maximum of 300). Many respondents responded in time traveled rather than miles, e.g., "it took us 3.5 hours to get here!" Time may be a more accurate measurement in future questionnaires.

Table 17

Demographic Q13 and Q14: Miles to Nearest Emergency *Department and the Assisted Ventilation Clinic (All Measures in Miles)*

Patient's Home to Destination	Mean	Median	Standard Deviation	Range	Minimum	Maximum
13) Miles to emergency department? (Q13)	10.39	5.00	12.43	59	1	60
14) Miles to Assisted Ventilation Clinic? (Q14)	58.81	38.50	56.62	300	0	300

Construct or Likert-type variables. Following the 14 demographic questions were the 24 Likert-type opinion questions. The means, standard deviations, skew and kurtosis of the 24 opinion variables are listed in Table 18. Questions 11, 15, 16, and 17 were negatively structured and were transposed by subtracting their original measures from 6 (e.g., neg11NeedDemo = [6- Q11NEEDEMO]) during data analysis in SPSS based on a 5 point scale. Many of the means were in the 4 (*Agree*) to 5 (*Strongly Agree*) range with standard deviations less than 1—these high means were associated with making caregiving and interacting with clinicians easier, providing better remote support, remote support being a good idea and wise, having obvious benefits and value, improving caregiving, solving problems more quickly, and intending to use if the service were available. Other questions with lower responses and more variance were associated with the unknowns of cost, training, learning to use, and how much support would be required. Negative skew and extremely positive kurtosis was prominent in rating telemedicine as being a good idea, wise, with obvious benefits where the means were above 4.32, skew was -1.233 or greater, and the kurtosis was 3 or greater.

Table 18

Likert-Type Opinion Questions Descriptive Statistics (Q1 to Q24)

Likert Variables	Mean*	Standard Deviation	Skew[1]	Kurtosis[2]
Make Caregiving Easier (Q1)	4.10	0.852	-1.173	2.165
Make Interacting with Clinicians Easier (Q2)	4.24	0.759	-1.248	3.12
Providing Better Remote Support (Q3)	4.33	0.733	-1.513	4.452
Easy to Use (Q4)	3.86	0.942	-0.809	0.513
I am Able to Use It (Q5)	3.95	0.996	-0.961	0.471
I have Videoconferencing Experience (Q6)	3.47	1.338	-0.546	-0.92
It's a Good Idea (Q7)	4.42	0.704	-1.504	3.793
It is Wise (Q8)	4.37	0.695	-1.233	3.006
The Benefits Are Obvious (Q9)	4.32	0.722	-1.313	3.166
I Can See the Value in It (Q10)	4.37	0.636	-1.27	4.699
I Don't Need a Demo (Q11)	2.61	1.23077	0.344	-0.983
It Will Be Useful in Caregiving (Q12)	4.20	0.735	-0.931	1.825
It Will Solve Problems Quickly (Q13)	4.26	0.732	-0.962	1.723
It will Make Caregivers More Effective (Q14)	4.20	0.755	-0.912	1.464
It Won't Take Time To Learn (Q15)	2.62	1.0761	0.42	-0.518
It Is Not Expensive (Q16)	3.43	1.01803	-0.57	-0.05
I Won't Need Support In Using It (Q17)	2.85	1.17971	0.15	-0.967
People Important to Me Think I Should Use It (Q18)	3.68	0.893	-0.331	0.20
People I Respect Think I Should Use It (Q19)	3.72	0.899	-0.403	0.230
People Who Influence Me Think I Should Use It (Q20)	3.67	0.88	-0.306	0.274
Vent Users Are Vulnerable to Equipment Failures (Q21)	3.72	1.138	-0.703	-0.223
Vent Users Are Susceptible to Infections and Mucus Buildup (Q22)	3.74	1.14	-0.739	-0.182
Vent Users Are at Risk of Serious Medical Emergencies (Q23)	3.78	1.181	-0.812	-0.191
Intent to Use Mobile Devices for Remote Mechanically-ventilated Patient Management (Q24)	4.06	.922	-1.219	1.820

1 – Skew Standard Error is 0.196; 2 – Kurtosis Standard Error is 0.39

* 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree

Evidence of reliability for Likert-type variables. The reliability analysis was performed using Cronbach's alpha with a result of 0.897 for the Likert variables combined (0.917 for standardized items). A Cronbach's alpha value greater or equal to 0.7 indicates construct validity and high reliability. The item-total statistics matrix indicates any variables that can be deleted to improve the overall Cronbach's alpha. However, no variable deletion could improve the Cronbach's alpha above the 0.897, an indication to keep all the variables.

Exploratory Factor Analysis of the Data Results

An exploratory factor analysis (EFA) was conducted to extract latent factors and to determine if they are consistent with the constructs as found in the literature. The process used to conduct this exploratory factor analysis is captured in the process diagram shown in Figure 24, by listing the steps taken in the EFA analysis.

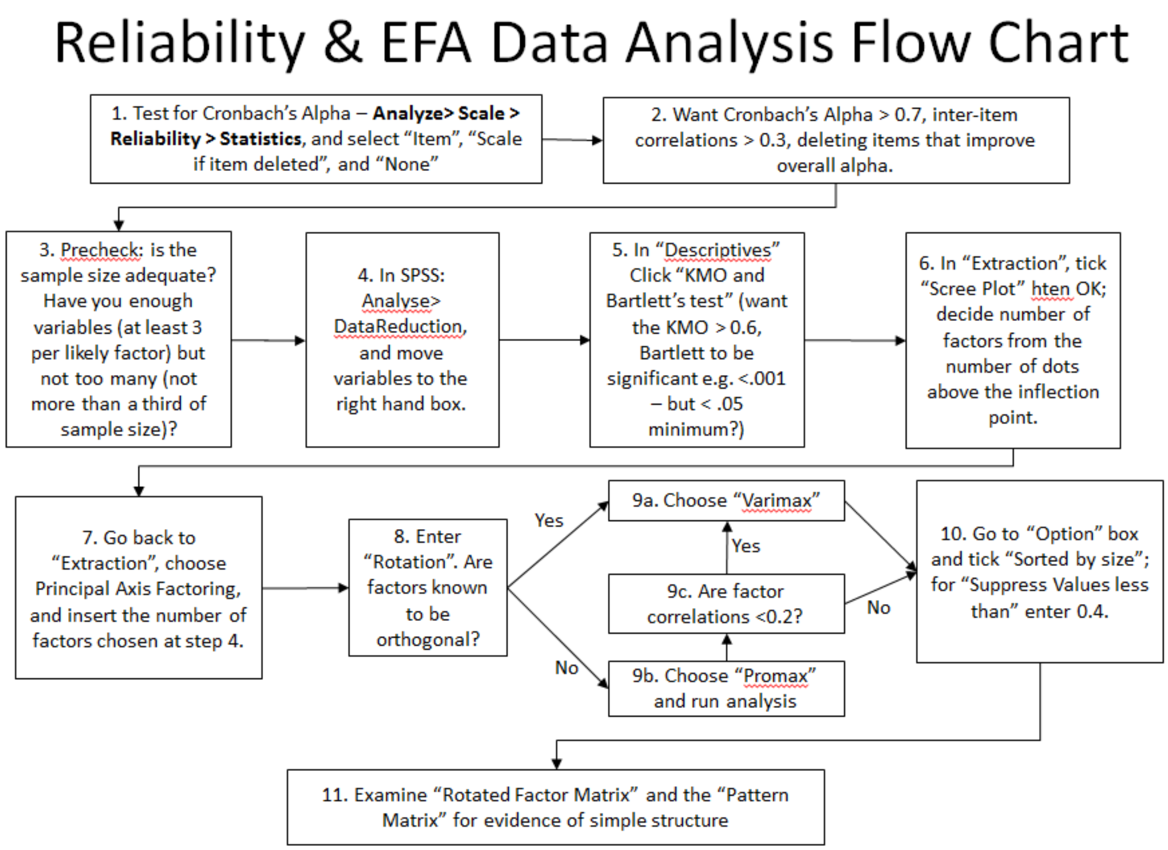


Figure 24. Exploratory factor analysis process diagram (adapted from Allen, 2017).

Principal component analysis was selected for the latent factor extraction. A scree plot was generated but was not useful in providing an inflection point above which to identify and select latent factors. For the initial factor extraction, no rotation was used to extract five latent factors based on eigenvalues greater than 1. The component matrix indicated some correlation between factors (an oblique rather than an orthogonal relationship), so the rotations oblimin and promax were tested to find the best fit. The pattern matrix provided the best indication of the Q1–Q24 variable mapping onto the five factors while blanking any data less than 0.3 provided easy identification of best fit matching of variables to the five factors. Once the factors and Q1–Q24 variables were matched with minimal between factor correlation or overlap, Cronbach's alpha reliability analysis was performed on each of the factors to verify good construct validity. During this analysis, non-contributing variables were examined to determine if their elimination would yield a higher alpha value and better construct validity.

The KMO and Bartlett's test results (Figure 25) were produced during the initial factor extraction. The KMO measure of sampling adequacy was 0.892 which indicated adequate data (anything over 0.6 is good). Bartlett's test of sphericity measured a significance level less than 0.001 (any value under .05 is adequate).

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.892
Bartlett's Test of Sphericity	Approx. Chi-Square	3158.788
	df	276
	Sig.	0.000

Figure 25. KMO and Bartlett's test from initial factor extraction

The initial factor extraction without rotations resulted in five latent factors or variables. These five factors explained about 75% of the variable variance. The component matrix analysis revealed some correlation indicating the five factors were not orthogonal. The oblique rotations, which include oblimin and promax, were used to find the best fit—the promax rotation provided the best results as shown in the pattern matrix in Table 19.

Table 19

Five-Factor Pattern Matrix from Principal Components and Rotated Promax Analysis

Pattern Matrix	Factor Component				
	1	**2**	**3**	**4**	**5**
Will Make Caregivers More Effective (Q14)	0.97				
Will Help Solve Problems More Quickly (Q13)	0.952				
I Can See the Value in Using It (Q10)	0.907				
I Can See the Benefits of Using It (Q9)	0.891				
It Is Wise (Q8)	0.882				
It Will Be Useful in Caregiving (Q12)	0.88				
It Is a Good Idea (Q7)	0.868				
It Will Provide Better Remote Support (Q3)	0.723				
It Will Make Caregiving Easier (Q1)	0.63				
Own/Access Mobile Device & Plan to Use It (Q24)	0.625				
It Will Make Interacting with Clinicians Easier (Q2)	0.499				0.405
People Who Influence Me Think I Should Use It (Q20)		0.975			
People Whose Opinions I Respect Think I Should Use It (Q19)		0.963			
People Important To Me Think I Should Use It (Q18)		0.931			
People Who Use Ventilators Are Vulnerable to Equipment Failures (Q22)			0.942		
People Who Use Ventilators Are Susceptible to Medical Emergencies (e.g. Infections) (Q21)			0.934		
People Who Use Ventilators Are at Risk of Serious Issues That Require Immediate Attention (Q23)			0.92		
It Will Take Time to Learn to Use It (Q15)				0.843	
I Will Need Support in Using It (Q17)				0.774	
I Will Need a Demo (Q11)				0.722	
It Is Expensive to Use Telemedicine (Q16)				0.599	
I Have Videoconferencing Experience (Q6)				0.525	
It Will Be Easy for Me to Use (Q4)					0.947
I Am Able to Use It (Q5)					0.837
Extraction method: principal component analysis. Rotation method: promax with Kaiser normalization. a. Rotation converged in 5 iterations					

The results of the five-factor component correlation matrix (refer to Table 20) listed the correlations between the five latent factors. Correlations ranged from .2 to .5 between Factors 1, 2, 3, and 5. Factor 4 had the least correlation with any of the other variables.

Table 20

Five-Factor Component Correlation Matrix

Component Correlation Matrix

Component	1	2	3	4	5
1	1	0.582	0.228	0.029	0.483
2	0.582	1	0.232	-0.045	0.336
3	0.228	0.232	1	0.214	0.19
4	0.029	-0.045	0.214	1	0.304
5	0.483	0.336	0.19	0.304	1

Extraction Method: Principal Component Analysis.
Rotation Method: Promax with Kaiser Normalization.

Completion of the identification of the five latent was followed by Cronbach's reliability analysis of each of the five latent factors as described in the next section.

Post factor extraction reliability analysis. A reliability estimate was calculated for each of the five latent factors. The deletion of the Q24 variable 24OAINTEND2USE (*own/access/intent to use*) from Factor 1 slightly increased the Cronbach's alpha. For Factors 1, 2, 3, and 5, the Cronbach's alpha results are shown in Table 21. The item-total matrix for these four factors indicated that no deletion of any Likert question variables would improve the alpha. All four factors had alpha values significantly above 0.7, indicating high reliability. Although Factor 4 had the lowest Cronbach's alpha measure, it was above 0.7, which satisfied the reliability requirement. Table 21 also lists the number of questionnaire questions that were associated with each factor.

Table 21

Five-Factor Cronbach's Alpha Reliability Statistics

Reliability Statistics			
	Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
Factor 1	0.956	0.957	10
Factor 2	0.959	0.959	3
Factor 3	0.93	0.93	3
Factor 4	0.754	0.756	5
Factor 5	0.905	0.906	2

Conclusion based on the factor analysis. Based upon the exploratory factor analysis factor extraction, a new model can be constructed that relates the 23 questions to each of the five new latent factors. This new model may represent a further development of the TAM model for use in settings similar to the one in this study. The additional factors generated by exploratory factor analysis, provide a framework for new items that will be useful in future research. The association of the 24 Likert questions with the five extracted factors is shown in a path diagram in Appendix K. To implement structural equation model analysis, at least 300 total respondents are required to provide adequate signal strength between variables.

Analysis of 24 Likert Variable Responses

A frequency analysis of the Likert responses to the 24 opinion questions revealed levels of agreement (in percent) with each of the 24 questions. Although the exploratory factor analysis extracted five factors, as a comparison, it was helpful to look at the raw Likert-scale responses. The responses (1 through 5) were grouped into three categories: agree (which includes all 4 and 5 responses, or agree and strongly agree, respectively), neutral (3), and disagree (which includes all 1 and 2 responses, disagree strongly and disagree, respectively). The number of responses in each category was divided by 153 (total responses for each question) and multiplied by 100. The questions were sorted by highest to lowest percentage of agreement with each question.

The percentage of agreement with each question created groupings (Figure 26). Questions with agreement in the 90% range (Q10, Q7, Q3, Q8, and Q9) revolved around opinions of the *concept* of using mobile devices for remote support. In the TAM model, these questions are mostly associated with *attitude*. Questions with agreement in the 80% range (Q2, Q13, Q12, Q14, and Q1) revolved around the idea of *how operationally* mobile device remote care would be beneficial. In the TAM model, these aligned strongly with *performance expectancy*, or how well they think the technology will increase their ability to perform their jobs.

Opinions on Concept of Using Mobile Devices for Remote Care

Q#	Question	SA or A (5 or 4)	Neutral (3)	D or SD (2 or 1)
Q10	I can see the value in it	96%	3%	1%
Q7	It's a good idea	93%	5%	2%
Q3	It will make remote support better	92%	6%	2%
Q8	It is wise	92%	7%	1%
Q9	The benefits are obvious	92%	5%	3%
Q2	Interacting w/clinicians will be easier	88%	10%	2%
Q13	Solve problems more quickly	88%	11%	1%
Q12	Useful in caregiving	87%	11%	2%
Q14	Make caregiving more effective	86%	12%	2%
Q1	Make caregiving easier	82%	14%	4%
Q24	Intend to Use	80%	14%	7%

Concept

How

Intent to Use

Likert Scale: 5=Strongly Agree, 4=Agree, 3=Neutral, 2=Disagree, 1=Strongly Disagree

Figure 26. Percentage of agreement with each of the 24 Likert opinion questions.

Respondents' ability to use the technology and pay for it is shown in Figure 27. These questions (Q5, Q4, Q6, Q11, Q15, Q17, and Q16) capture the respondents' opinions about their ability to use the technology, their experience using it, their need for support, the learning required, or their ability to pay for it. These questions were grouped in the category Hands-On/Ability. In the TAM model, these types of questions are most closely associated with Self-Efficacy.

Respondent's Ability to Use the Technology & Cost

Q#	Question	SA or A (5 or 4)	Neutral (3)	D or SD (2 or 1)	
	Ability to Perform or Support Needed				Hands-On/Ability
Q5	I am able to use it	76%	12%	11%	
Q4	It will be easy for me to use	72%	19%	9%	
Q6	I have videoconferencing experience	59%	14%	27%	
Q11	I will need a demo	54%	17%	29%	
Q15	It will take time to learn	52%	25%	22%	
Q17	I will need support to use it	44%	22%	33%	
	Cost				
Q16	It is expensive ↑$	17%	29%	54%	↓$

Likert Scale: 5=Strongly Agree, 4=Agree, 3=Neutral, 2=Disagree, 1=Strongly Disagree

Figure 27. Respondent's ability to use the technology.

The remaining questions grouped into the sub-constructs *health beliefs* and *social influence* Figure 28. Health beliefs showed a progressive increase from disagree to agree. This aligned with the variation in the AVC population. Those responding 2 (*disagree)* aligned with the AVC population that are new to the clinic and may not have experienced vulnerabilities, susceptibilities, and risks associated with equipment issues or medical emergencies. At the other end, those in the *agree* category comprised those using ventilators 24/7 or those having experienced equipment or medical emergencies and tended to agree with health beliefs raised by these questions (Q23, Q22, and Q21). This opinion was confirmed based upon responses observed while people were completing the questionnaire. Social influence (Q19, Q18, and Q20) indicated low percentages of disagreement and moderate agreement and neutrality. To some, the telemedicine concept was new and they had no idea how others would advise them. However, many patients and caregivers sitting together in the clinic rooms provided each other reinforcing confirmation that this was a valuable service and they should use it.

Health Beliefs and Social Influence

Q#	Question	SA/A (5/4)	N (3)	D/SD (2/1)
	Health Beliefs	Advanced Stages		Early Stages
Q23	People who use ventilators are **vulnerable to equipment failures, alarms, or incorrect settings**	67%	18%	16%
Q22	People who use ventilators are **susceptible to medical emergencies (infections, mucus buildup)**	65%	20%	15%
Q21	People who use ventilators are **at risk of serious issues requiring immediate medical attention**	63%	22%	15%
	Social Influence			
Q19	People **important to me** think I should use it	59%	35%	6%
Q18	People whose **opinions I respect** think I should use it	57%	37%	6%
Q20	People who **influence me** think I should use it	56%	39%	5%

Likert Scale: 5=Strongly Agree, 4=Agree, 3=Neutral, 2=Disagree, 1=Strongly Disagree

Figure 28. Sub-constructs *Health Beliefs* and *Social Influence.*

A comparison of the five factors extracted in the exploratory factor analysis and the question groupings resulting from the Likert question agreement percentages aligned in similar ways as shown in Table 22. The two original main TAM constructs were *perceived ease of use* (comprised of sub-constructs *effort expectancy*, *self-efficacy*, *attitude*, and *visibility*) and *perceived usefulness* (comprised of sub-constructs *response cost*, *performance expectancy*, *social influence/norm*, and *health beliefs*). The results of both exploratory factor analysis and Likert response sorting by agreement do not divide into two distinct groups (e.g., *perceived ease of use* and *perceived usefulness*) but into five different groups. These factors also only explain 75% of the variable variance. Efforts to make the questionnaire short and concise may have eliminated variables that could more fully explain *intent to use.*

Table 22

Comparison of the Five EFA Extracted Factors Versus Likert Agree Percent Sort

Exploratory Factor Analysis		***Sorting by Likert Responses and % that Agree - Highest to Lowest***					
Extracted Factor	**Associated Questions**	**Opinion Label**	**Question / Wording**		**SA(5) or A(4)**	**Neutral**	**D(2) or SD(1)**
Factor 1	Q10, Q9, Q8, Q13, Q14, Q7, Q12, Q3, Q1, Q2	Concept (Attitude)	Q10	I can see the value in it	96%	3%	1%
			Q7	It's a good idea	93%	5%	2%
			Q3	It will make remote support better	92%	6%	2%
			Q8	It is wise	92%	7%	1%
			Q9	The benefits are obvious	92%	5%	3%
		How done operationally (Performance Expectancy)	Q2	Interacting w/clinicians will be easier	88%	10%	2%
			Q13	Solve problems more quickly	88%	11%	1%
			Q12	Useful in caregiving	87%	11%	2%
			Q14	Make caregiving more effective	86%	12%	2%
			Q1	Make caregiving easier	82%	14%	4%
N/A	Q24	Intent to Use	Q24	Intend to Use	80%	14%	7%
Factor 5	Q4, Q5	Hands-On/ Ability (Self-Efficacy)	Q5	I am able to use it	76%	12%	11%
			Q4	It will be easy for me to use	72%	19%	9%
				People who use ventilators are:			
Factor 3	Q22, Q21, Q23	Health Beliefs	Q23	at risk of serious issues requiring immediate medical attention	67%	18%	16%
			Q22	susceptible to medical emergencies (infections, mucus buildup)	65%	20%	15%
			Q21	vulnerable to equipment failures, alarms, or incorrect settings	63%	22%	15%
Factor 4	Q6	Hands-On/ Ability (Self-Efficacy)	Q6	I have videoconferencing experience	59%	14%	27%
Factor 2	Q20, Q19, Q18	Social Influence	Q19	People whose opinions I respect think I should use it	59%	35%	6%
			Q18	People important to me think I should use it	57%	37%	6%
			Q20	People who influence me think I should use it	56%	39%	5%
Factor 4	Q15, Q17, Q11, Q16, Q6	Hands-On/Ability (Self-Efficacy)	Q11	I will need a demo	54%	17%	29%
			Q15	It will take time to learn	52%	25%	22%
			Q17	I will need support to use it	44%	22%	33%
			Q16	It is expensive	17%	29%	54%

Hands-on/ability (or *self-efficacy*) aligns well with *perceived ease of use. Concept* (or *attitude), how operationally* (or p*erformance expectancy)* align well with *perceived usefulness.* However, *health beliefs* and *social influence* do not fit well with *perceived usefulness* or *perceived ease of use* but clearly impact *intent to use.* These results suggest a different model than the TAM framework originally proposed. Also, discovery of additional variables would be valuable in explaining unaccounted for variance *intent to use.*

Inferential Results

Hypotheses test results for $H1_0$–$H6_0$ and $H7.1_0$–$H7.14_0$ are presented in this section. The hypotheses are stated, the data analysis is provided and discussed, and the final result of each null hypothesis test is indicated. The hypotheses were either significant, not significant, or had potential significance based upon statistical results. To clarify, the null hypotheses are tested and if there is significant evidence that a null hypothesis is rejected, the alternative hypothesis is accepted.

$H1_0$ hypothesis test results: *perceived usefulness* → *intent to use*. Hypothesis $H1_A$ states that there is a significant relationship between *perceived usefulness* and patients' and caregivers' *intent to use* mobile devices for remote ventilated patient management (refer to Table 23). Both the Pearson and Spearman's rho correlation coefficients confirm that there is a significant relationship between *intent to use* and *perceived usefulness* with correlations of 0.540 and 0.541, respectively, with a less than .001 significance level using a 2-tailed test. $H1_0$ is rejected providing evidence that $H1_A$ is true.

Table 23

$H1_0$ Hypothesis Results—Perceived Usefulness and Intent to Use (Pearson and Spearman's rho Correlations)

First Interval Variable	**Second Interval Variable**	**Pearson Correlation Coefficient**	**Significance (2-tailed)**	**Spearman's rho Correlation Coefficient**	**Significance (2-tailed)**
Intent to Use	*Perceived Usefulness*	0.540**	.001	0.541**	.001
Null Hypothesis Result		Rejected		Rejected	

Note: **Correlation significant at the .01 level (2-tailed)

$H2_0$ hypothesis test results: *perceived ease of use* → *intent to use*. Hypothesis $H2_A$ states that there is a significant relationship between *perceived ease of use* and patients' and caregivers' *intent to use* mobile devices for remote ventilated patient management (refer to Table 24). Both the Pearson and Spearman's rho correlation coefficients confirm that there is a significant relationship between *perceived ease of use* and *intent to use* with correlations of 0.518 and 0.470, respectively, with a less than .001 significance level using a 2-tailed test. $H2_0$ is rejected providing evidence that $H2_A$ is true.

Table 24

$H2_0$ Hypothesis Results—Perceived Ease of Use and Intent to Use (Pearson and Spearman's rho Correlations)

First Interval Variable	**Second Interval Variable**	**Pearson Correlation Coefficient**	**Significance (2-tailed)**	**Spearman's rho Correlation Coefficient**	**Significance (2-tailed)**
Intent to Use	*Perceived Ease of Use*	0.518**	.001	0.470**	.001
Null Hypothesis Result		Rejected		Rejected	

Note: **Correlation significant at the .01 level (2-tailed)

$H3_0$ hypothesis test results: *perceived ease of use* → *perceived usefulness*. Hypothesis $H3_A$ states that there is a significant relationship between *perceived ease of use* and *perceived usefulness* mobile devices for remote ventilated patient management (refer to Table 25). Both the Pearson and Spearman's rho correlation coefficients confirm that there is evidence of a significant relationship between *perceived ease of use* and *perceived usefulness* with correlations coefficients of 0.716 and 0.663, respectively, with a less than .001 significance level using a 2-tailed test. $H3_0$ is rejected providing evidence that $H3_A$ is true.

Table 25

$H3_0$ Hypothesis Results—Perceived Ease of Use and Perceived Usefulness (Pearson and Spearman's rho Correlations)

First Interval Variable	Second Interval Variable	Pearson Correlation Coefficient	Significance (2-tailed)	Spearman's rho Correlation Coefficient	Significance (2-tailed)
Perceived Ease of Use	*Perceived Usefulness*	0.716**	.001	0.663**	.001
Null Hypothesis Result		Rejected		Rejected	

Note: **Correlation significant at the .01 level (2-tailed)

$H4_0$ hypothesis test results: *own/access* → *perceived usefulness*. Hypothesis $H4_A$ states that there is a significant relationship between *own/access* of mobile devices and *perceived usefulness* in using mobile devices for remote ventilated patient management (refer to Table 26). Both the Pearson and the paired samples correlation coefficients confirm that there is a significant relationship between *own/access* and *perceived usefulness* with correlation coefficients of 0.242 and 0.242, respectively, and 2-tailed significance at the 0.003 level. $H4_0$ is rejected providing evidence that $H4_A$ is true.

Table 26

$H4_0$ Hypothesis Results of Perceived Usefulness and Own/Access (Pearson and Paired Samples Correlation)

First Interval Variable	Second Interval Variable	Pearson Correlation Coefficient	Significance (2-tailed)	Paired Samples Correlation Coefficient	Significance (2-tailed)
Perceived Usefulness	*Own/Access*	0.242**	.003	0.242**	.003
Null Hypothesis Result		Rejected		Rejected	

Note: **Correlation significant at the .01 level (2-tailed)

$H5_0$ hypothesis test results: *own/access* → *perceived ease of use*. Hypothesis $H5_A$ states that there is a significant relationship between *own/access* of mobile devices and *perceived ease of use* in using mobile devices for remote ventilated patient management (refer to Table 27). Both the Pearson and the paired samples correlation coefficients confirm that there is a significant relationship between *own/access* and *perceived ease of use* with correlation coefficients of 0.233 and 2-tailed significance at the 0.004 level for both tests. $H5_0$ is rejected providing evidence that $H5_A$ is true.

Table 27

$H5_0$ Hypothesis Results—Perceived Ease of Use and *Own/Access (Pearson and Paired Samples Correlations)*

First Interval Variable	Second Interval Variable	Pearson Correlation Coefficient	Significance (2-tailed)	Paired Samples Correlation Coefficient	Significance (2-tailed)
Perceived Ease of Use	*Own/Access*	0.233**	.004	.233**	.004
Null Hypothesis Result		Rejected		Rejected	

Note: **Correlation significant at the .01 level (2-tailed)

H6$_0$ hypothesis test results: *own/access* → *intent to use*. Hypothesis H6$_A$ states that there is a significant relationship between *own/access* of mobile devices and *intent to use* in using mobile devices for remote ventilated patient management (refer to Table 28). Both the Pearson and the paired samples correlation coefficients confirm that there is no significant relationship between *own/access* and *intent to use* with correlation coefficients of -0.011 and 2-tailed significance at the 0.895 level for both tests. Thus, H6$_0$ is accepted; there is no significant relationship between ownership or access (*own/access*) to mobile devices and *intent to use* them for remote ventilated patient management.

Table 28

H6$_0$ Hypothesis Results—Own/Access and Intent to Use (Pearson and Paired Samples Correlations)

First Interval Variable	Second Interval Variable	Pearson Correlation Coefficient	Significance (2-tailed)	Paired Samples Correlation Coefficient	Significance (2-tailed)
Own/Access	*Intent to Use*	-0.011	0.895	-0.011	0.895
Null Hypothesis Result		Accepted		Accepted	

Note: **Correlation significant at the .01 level (2-tailed)

Overview of H7.1$_0$ Through H7.14$_0$ Null Hypotheses Test Results.

Hypotheses H7.1$_0$ through H7.14$_0$ are grouped into different analysis groups based upon the type of data being analyzed. H7.1$_0$ states that there are no differences between the various respondents, patients, family and friend caregivers, and professional caregivers, in terms of their *intent to use* mobile devices for remote ventilated patient management—these relationships are tested using an ANOVA. H7.2/6/13/14$_0$ state there is no relationship between age, ventilator hours per day, and miles to the emergency department and miles to the Assisted Ventilation Clinic, and *intent to use*—the Pearson correlation is used to analyze this interval data. $H7.4/5_0$ states there is no relationship between the patients' diagnoses and respiratory assist devices and the respondents' *intent to use*—these are categorical or nominal versus rank analysis uses the Kendal tau test. Finally, several dichotomous/interval variables (Q3 sex, Q7 tracheostomy, Q8 *own/access* to mobile devices, Q9 used videoconferencing before, Q10 downloaded apps before, and A12 cellular/WiFi/Internet access in the patient's home) for $H7.3_0$, $H7.7_0$, $H7.8_0$, $H7.9_0$, $H7.10_0$, and $H7.12_0$ are analyzed using the point biserial correlation test (which is a subset of the Pearson correlation test).

$H7.1_0$ hypotheses test results: patient, family or friend caregiver, professional caregiver → *intent to use*. Hypothesis $H7.1_0$ states there are no differences between the three groups (patients, family and friend caregivers, and professional caregivers) and their *intent to use* mobile devices for remote ventilated patient management (refer to Table 29). Results shown in Table 29 indicate there are indeed no differences in the three groups based upon their *intent to use* mobile devices for ventilated patient management. Although patients were very close to being significantly different than the caregivers in terms of *intent to use*, all groups were the same based upon the ANOVA test with significance at the 0.05 level measured at 0.057, 0.374, and 0.743, respectively. Thus, respondent groups do not indicate any significant difference with respect to *intent to use*; all three groups are the same.

Table 29

H7.1$_0$ Hypothesis Results—Patients, Family/Friend/Professional Caregivers and Intent to Use (ANOVA)

ANOVA – Comparing Patients, Family or Friend Caregivers, and Professional Caregivers to *Intent to Use* (Null Hypotheses—groups are the same)						
Respondent	**Grouping**	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Patients vs. *Intent to Use*	Between Groups	7.122	4	1.781	2	0.057
	Within Groups	50.001	68	0.735		
	Total	57.123	72			
Family or Friends Caregivers vs. *Intent to Use*	Between Groups	2.744	3	0.915	1	0.374
	Within Groups	46.635	54	0.864		
	Total	49.379	57			
Professional Caregivers vs. *Intent to Use*	Between Groups	0.833	2	0.417	0	0.743
	Within Groups	26.258	19	1.382		
	Total	27.091	21			

H7.2$_0$ (age), H7.6$_0$ (vent hours/day), H7.13$_0$ (miles to ED), H7.14$_0$ (miles to Assisted Ventilation Clinic) → *intent to use* null hypotheses test results. These hypotheses state that there is no significant relationship between these variables measured with demographic questions Q2, Q6, Q13, and Q14 and *intent to use* (refer to Table 30). Using the Pearson Correlation test, age, vent hours/day, miles to emergency department (ED), and miles to Assisted Ventilation Clinic resulted in Pearson correlation coefficients of 0.012, 0.381, 0.044, and 0.084 and 2-tailed significance levels of 0.887, 0.071, 0.57, and 0.305, respectively. All these null hypotheses were accepted with no evidence for the alternative being true. There is no evidence to support the alternative hypotheses that there is a correlation with *intent to use* mobile devices for remote ventilated patient management.

Table 30

H7.2$_0$, H7.6$_0$, H7.13$_0$, H7.14$_0$ Hypotheses Results—Intent to Use and Age, Vent Hours, Miles to Emergency Department and Assisted Ventilation Clinic (Pearson Correlation)

H#. Q #	Null Hypothesis (No Strong Relationship Between)	Pearson Correlation	Significance (2-Tailed)	Outcome of Test
H7.2$_0$	Age => *Intent to Use*	.012	0.887	Accepted
H7.6$_0$	Hours on Ventilator => *Intent to Use*	.381	0.071	Accepted
H7.13$_0$	Miles from Patient's Home to Emergency Department => *Intent to Use*	.044	0.587	Accepted
H7.14$_0$	Miles from Patient's Home to Assisted Ventilation Clinic => *Intent to Use*	.084	0.305	Accepted

H7.3$_0$ (sex), H7.7$_0$ (tracheostomy), H7.8$_0$ (*own/access*), H7.9$_0$ (videoconference before), H7.10$_0$ (downloaded app before), H7.12$_0$ (cellular/WiFi/Internet connectivity) →*intent to use* null hypotheses test results. These hypotheses state that there is a significant relationship between the dichotomous variables sex, having a tracheostomy, owning or having access to a mobile device, using videoconferencing before, downloading applications before, or having cellular/WiFi/Internet access in the patient's home is correlated with *intent to use*. However, using the point biserial correlation test, a special version of the Pearson correlation test, all these variables failed to have a significant correlation relationship with *intent to use* at the 0.05 significance level testing (refer to Table 31).

Table 31

H7.3$_0$/7/8/9/10/12$_0$ Point Biserial Hypotheses Testing of Sex, Trach, Own/Access, VC Before, Download Apps Before, and Cellular/WiFi/Internet Access Versus Intent to Use

H#. Q #	**Null Hypothesis (No Strong Relationship Between)**	**Pt. Biserial Correlation**	**Significance (2-Tailed)**	**Outcome of Test**
H7.3$_0$	Sex => *Intent to Use*	0.042	0.610	Accepted
H7.7$_0$	Having a Tracheostomy => *Intent to Use*	0.088	0.281	Accepted
H7.8$_0$	*Own/Access* => *Intent to Use* (See H6 Analysis)	-0.083	0.311	Accepted
H7.9$_0$	Used Videoconferencing Before=> *Intent to Use*	0.058	0.477	Accepted
H7.10$_0$	Downloaded Applications Before => *Intent to Use*	0.121	0.137	Accepted
H7.12$_0$	Patient has Cellular/WiFi/Internet Access => *Intent to Use*	0.150	0.064	Accepted

H7.4$_0$ (diagnoses), H7.5$_0$ (respiratory assist device type) hypotheses → *intent to use* test results. Test results of using the Kendall's tau rank order to measure correlation between categorical/ordinal variables diagnoses and respiratory device types indicated that there is not a significant relationship between these variables and *intent to use* mobile devices for remote ventilated patient management (refer to Table 32). Thus, H7.4$_0$ and H7.5$_0$ are accepted, and there is no evidence that the alternative hypotheses are true.

Table 32

H7.4$_0$/5$_0$ Hypotheses Kendall's Tau Analysis of Diagnosis and Respiratory Assist Device Type Versus Intent to Use

H#. Q #	**Null Hypothesis (No Strong Relationship Between)**	**Kendall's Tau Correlation**	**Significance (2-Tailed)**	**Outcome of Test**
H7.4$_0$	Diagnosis => *Intent to Use*	0.054	0.510	Accepted
H7.5$_0$	Respiratory Assist Device Type => *Intent to Use*	-0.020	0.802	Accepted

H7.11a_0 (mobile device *own/access*), H7.11b_0 (number of devices own/access) → *intent to use* hypotheses test results. The Pearson correlation test was used to analyze any significant relationships between interval data variables mobile device ownership or access and the number of devices owned accessible versus *intent to use*. Based upon 2-tailed significance testing, there is not a significant relationship between these variables in H7.11a_0 and H7.11b_0 and *intent to use*. Thus, H7.11a_0 and H7.11b_0 are accepted as shown in Table 33.

Table 33

H7.11a_0 and b_0 Point Biserial/Pearson Correlation of Own/Access and Number of Devices Owned Versus Intent to Use

H#. Q #	Null Hypothesis (No Strong Relationship Between)	Pearson Correlation	Significance (2-Tailed)	Outcome of Test
H7.11a_0	Alternate *Own/Access* Mobile Devices from Q11 => *Intent to Use*	0.102	0.208	Accepted
H7.11b_0	Number of Devices Respondent Owns/Access => *Intent to Use*	0.101	0.215	Accepted

Summary of Results

Characteristics of the sample. A convenience sample (n = 153) from a population of approximately 670 patients and 1,340 caregivers comprised an equal number of patients (73) and caregivers (80). One caregiver was 16 years old while the oldest was 77. Patient age ranged from 21 to 77. Female caregivers outnumbered males, by 41:17 (family or friend) and 20:2 (professional). Although the top two diagnoses were muscular dystrophy and spinal cord injuries, the majority of respondents chose *Other* indicating significant diagnosis diversity—in fact, 43 different types of diagnosis were listed. The diversity of respiratory assist devices used by the patients emphasizes the complexity of care and diversity of knowledge required to support a variety of mechanical ventilators—14 different types of respiratory devices were indicated by respondents. Ventilator use peaks at 1, 9, and 24 hours per day which relates to new users, use for sleep, and 24/7 use. Thirty-three percent of respondents indicated involvement of a tracheostomy. Some respondents traveled approximately 300 miles to the visit the AVC.

The majority of respondents had access to mobile devices, experience downloading applications and using videoconferencing, had connectivity in the patient's home, and intended to use their infrastructure for remote mechanically-ventilated patient management. Of the 153 respondents, 16 did not have either an Apple or Android brand smartphone or tablet (90.1% did), 8 did not have any type of mobile device (95% did), and only 2 respondents didn't have any type of ICT. Cellular/WiFi/Internet access was pervasive across the respondents with 96.1% connectivity.

Characteristics of the instrumentation. Measures of description and reliability were high. Cronbach's alpha indicated reliability was high for the 24 Likert questions with a measure of 0.897 (over 0.7 is good). Eleven means (of the 24 Likert variables) had values between 4 (*Agree*) and 5 (*Strongly Agree*) relative to positive aspects of telemedicine. Exploratory factor analysis explored the raw Likert data collected and extracted five latent factors—all had reliability measures > 0.7 and four were above 0.9 which indicated an alternate model to the TAM model may better fit the data and this population.

Hypothesis testing summary. Hypotheses testing (see Table 34) used the Pearson product moments, Spearman, point biserial, and Kendall's tau tests to measure correlation between 23 Likert variables and *intent to use* and also between 14 demographic variables and *intent to use. Perceived ease of use* and *perceived usefulness* were significantly correlated with each other and with both *intent to use* and *own/access* to mobile devices (at a significance level $p < .001$). The rest of the null hypotheses tests were accepted (not significant evidence for the alternative hypotheses) except for two that were close and indicated potential significance and worth further investigation in future research. They were *vent hours/day* and *connectivity* which measured 0.071 and 0.064, respectively.

Table 34

Summary of Hypotheses Testing Results in Terms of the Alternative Hypotheses

Hypo-theses	**Alternative Hypotheses**	**Measures**	**Signifi-cance**	**Result**
$H1_A$	*Perceived Usefulness* → *Intent to Use*	0.540	.001	Significant
$H2_A$	*Perceived Ease of Use* → *Intent to Use*	0.518	.001	Significant
$H3_A$	*Perceived Ease of Use* → *Perceived Usefulness*	0.716	.001	Significant
$H4_A$	*Own/Access* → *Perceived Usefulness*	0.242	.003	Significant
$H5_A$	*Own/Access* → *Perceived Ease of Use*	0.233	.004	Significant
$H6_A$	*Own/Access* → *Intent to Use*	-0.011	0.895	Not Sig.
$H7.1_A$	Respondent (Pts/CGFF/CGP) → *Intent to Use*	ANOVA Results	.057/ .374/ .743	Not Sig.
$H7.2_A$	Age → *Intent to Use*	.012	0.887	Not Sig.
$H7.3_A$	Sex → *Intent to Use*	0.042	0.610	Not Sig.
$H7.4_A$	Diagnoses → *Intent to Use*	0.054	0.510	Not Sig.
$H7.5_A$	Respiration Assist Device → *Intent to Use*	-0.020	0.802	Not Sig.
$H7.6_A$	Vent Hrs/Day → *Intent to Use*	.381	0.071	Potential Significance
$H7.7_A$	Tracheostomy → *Intent to Use*	0.088	0.281	Not Sig.
$H7.8_A$	*Own/Access* → *Intent to Use*	-0.083	0.311	Not Sig.
$H7.9_A$	Videoconference B 4 → *Intent to Use*	0.058	0.477	Not Sig.
$H7.10_A$	Download Apps B4→*Intent to Use*	0.121	0.137	Not Sig.
$H7.11a_A$	*Own/Access* Mobile Devices → *Intent to Use*	0.102	0.208	Not Sig.
$H7.11b_A$	# Devices → *Intent to Use*	0.101	0.215	Not Sig.
$H7.12_A$	Connectivity → *Intent to Use*	0.150	0.064	Potential Significance
$H7.13_A$	Miles to Emergency Department → *Intent to Use*	.044	0.587	Not Sig.
$H7.14_A$	Miles to Assisted Ventilation Clinic → *Intent to Use*	.084	0.305	Not Sig.

Note: Not Sig. = Not Significant

Many models were examined in the literature review, analyzed, and distilled down to the one used in this study based on technology acceptance and health belief models. It was used to create a questionnaire instrument to collect demographic and opinion data. This data was analyzed to discover any significant relationships between them and their potential relationship to *intent to use* mobile technologies for remote patient support. A transition to Chapter 5, Conclusions and Recommendations, will now allow the examination of these results in a broader context, their relationship to other related research, and potential new avenues of future quantitative and qualitative research to advance telemedicine.

Chapter 5: Conclusions and Recommendations

Introduction

This chapter summarizes conclusions, theoretical and practical implications, and recommendations based upon the results presented in Chapter 4. These descriptive and inferential results, generated from collected and analyzed questionnaire data, provide the basis for describing the patient- and caregiver-owned mobile device infrastructure, their experience levels, the level of cellular/WiFi/Internet connectivity, and most importantly, their *intent to use* telemedicine services provided by the Michigan Medicine health system. Results illuminated sub-populations of the Michigan Medicine adult Assisted Ventilation Clinic (AVC) including their motivations and barriers in using eHealth services. These results also pointed to some recommendations that may be of value to clinical administrators as they decide how to fully implement eHealth services in the AVC. Finally, suggestions for further research are presented as pathways to gain additional understanding and evidence in how best to utilize mobile devices for remote mechanically-ventilated patient management.

Overview of Study

A total of 670 AVC patients (most using some form of mechanical ventilation) and their family/friend/professional caregivers are supported at a lower cost in their homes rather than in the more expensive alternative hospital or nursing home. Their care is complex. When telephone-only remote support is unable to resolve equipment or medical issues, patients are often transported 100s of miles to the AVC. The alternative is going to the nearest emergency department where they may receive treatment that is expensive, often excessive or unnecessary, or they may even be hospitalized. Mobile device videoconferencing offers a more powerful solution for remote care but must rely upon a patient/caregiver-owned mobile device infrastructure, connectivity, and experience. The extent of this infrastructure was unknown, their mobile device experience was unknown, and their *intent to use* telemedicine services was also unknown.

Based on the technology acceptance model (TAM) framework (Davis, 1989), a technology acceptance model framework which included *perceived ease of use*, *perceived usefulness*, and *intent to use* provided a preliminary starting point for hypotheses formation, data collection, testing, and analysis of data using SPSS to measure correlation between these variables. Data were also collected using 14 demographic questions and 24 Likert-type opinion questions to measure patient and caregiver *intent to use* telemedicine, the extent of the patient/caregiver owned mobile device infrastructure including connectivity, and their experience using those devices.

Correlation testing was performed on the 14 demographic and 23 Likert variables versus the 24^{th} question (Q24) measuring *intent to use.* Inferential results ($H1_0$–$H5_0$) indicated significant correlation between *perceived ease of use, perceived usefulness,* and *intent to use*; between *own/access* to mobile devices and *perceived ease of use* and *perceived usefulness* ($H4_0$ and $H5_0$), but not between hypotheses ($H6_0$, $H1_0$–$H6_0$, and $H7.1_0$–$H7.14_0$) testing of the 14 demographic variables (such as mobile device *own/access*, miles to travel to the emergency department or AVC, experience, age, having a tracheostomy, or other variables) and *intent to use*.

Descriptive results included characteristics of the AVC sample population. Of 188 people asked to complete the questionnaire, 153 (n = 153) actually completed the questionnaire for an 81% response rate. Additional descriptive variable analysis included exploratory factor analysis and Likert sorting of variables based upon percent of agreement with *intent to use.* Both exploratory factor analysis (EFA) and Likert sorting resulted in five variables to explain 75% of the variance among the responses. This pointed to a potential alternate model to the TAM to explain the AVC data collected. Sub-populations of the AVC can be grouped into five categories based upon positive and negative characteristics associated with *intent to use*.

Conclusions

The demographic questions resulted in a rich set of characteristics describing the sample population. There were no differences between patients, family or friend caregivers, and professional caregivers in terms of *intent to use* telemedicine. However, family or friend caregivers (CGFF) outnumbered professional caregivers (CGP) by a count of 3:1. The age span of caregivers ranged from 16 up to 75. Females outnumbered male caregivers by a count of 41:17 (CGFF), and 20:2 (CGP).

Mechanical ventilation was a key focus of the study which collected data on patient diagnoses, types of respiratory devices, and ventilator usage patterns. Muscular dystrophy (24.2%) and spinal cord injuries (21.6%) were the dominant diagnoses indicated followed by ALS (9.2%), cerebral palsy (CP) (6.2%), and myopathy (4.6%). However, 32.8% of the diagnoses were specified as *Other*, which indicates the diversity and complexity of the patients' conditions. The respiratory assist devices Trilogy, BiPAP, CPAP, LTV, and Astral ventilators are used by over 60% of the patients while 27% use a cough assist or mucus clearing device. There were also a variety of other types of devices used (e.g., Sip & Puff, AVPS, A-PAP, and vibrating vests to name a few). Neither diagnoses nor respiratory device types were significantly correlated with *intent to use* telemedicine. Ventilator hours per day ranged from 0 to 24 hours with spikes at 0–2 for new users, around nine hours used mainly during sleep, and 24 hours for those using ventilators 24/7. Ventilator hours were not significantly correlated with *intent to use* telemedicine. Approximately 33% of the sample population had a tracheostomy, which corresponded to the overall tracheostomy frequency for the total AVC population.

Mobile device ownership or access (*own/access*) was a critical piece of information needed to determine the extent of the patient/caregiver-owned infrastructure. Several dichotomous demographic variables captured this data: mobile device *own/access*, videoconferencing experience, experience downloading applications, and cellular/WiFi/Internet access. Importantly, 90.8% of the respondents either owned or had access to mobile devices, 68% had used videoconferencing before, 77% had downloaded applications before, and 96% had cellular/WiFi/Internet access in the patient's home. However, none of these dichotomous variables was significantly correlated with *intent to use*. Information and communication technology (ICT) ownership was significant among patients and caregivers. Only 2 respondents out of 153 did not own some type of ICT. Multiple device ownership was very common—80% owned two or more ICT devices among the 153 respondents with ownership ranging from one device (30 respondents), two devices (50 respondents), three devices (41 respondents), four devices (26 respondents), up to five devices owned (four respondents). Only 15 of the 153 respondents did not own or have access to an Apple or Android smartphone or tablet—only eight did not have access to any type of mobile device (smartphone or tablet) at all. Although device ownership or access (*own/access)* was pervasive, it was not significantly correlated with *intent to use*.

Travel was a potential key demographic that could have indicated a strong *intent to use*—assuming it takes a long time to reach a point of care. The demographic questions “miles to emergency department” (Q13) and “miles to the AVC” (Q14) collected data on miles collected distance traveled to these locations—some patients preferred to indicate time rather than miles. The nearest emergency department ranged from 1 to 59 miles with a mean of 10 miles while the distance from the patient’s home to the Assisted Ventilation Clinic ranged from 0 to 300 miles with an average of 59 miles. Distance to travel to either the nearest emergency department or the Assisted Ventilation Clinic was not a strong indicator of *intent to use* with both having insignificant correlations. Travel distance to receive care did not significantly correlate with *intent to use.*

Likert questions Q1 to Q23 were grouped with Q1 to Q11 measuring *perceived ease of use* and Q12 to Q23 measuring *perceived usefulness*. Both *perceived ease of use* and *perceived usefulness* were strongly correlated with *intent to use* as well as being strongly correlated with each other at the significance level of less than p = .001 (as indicated by $H1_0$–$H3_0$ testing). Also, mobile device ownership or access was strongly correlated with *perceived ease of use* and *perceived usefulness* at the less than 0.001 level (null hypotheses $H4_0$ and $H5_0$). However, *own/access* was not significantly correlated with *intent to use* (null hypothesis $H6_0$). Individual demographic variables 1 through 14, which were analyzed in hypotheses $H7.1_0$ through $H7.14_0$, did not indicate any significant correlation with *intent to use* mobile device videoconferencing for mechanically-ventilated patient management.

An exploratory factor analysis was performed using the data collected in the Likert questions Q1 through Q23 to check construct validity of the TAM framework. Five latent factors were extracted using SPSS Version 24 exploratory factor analysis, principal components analysis, and the promax oblique rotation. Reliability analysis of the five extracted factors using Cronbach’s alpha indicated Factors 1, 2, 3, and 5 all had alpha’s greater than 0.900, while Factor 4 was less reliable but still had an alpha of 0.754, which was still acceptable. In parallel, Likert variable sorting based upon percentage agreement with the question also resulted in five factors with overlap of the five EFA extracted factors. Results are discussed more in theoretical implications.

Theoretical Implications

It may be helpful to get a 30,000 foot view of acceptance/adoption models (technology and health) before examining the success of the TAM framework in this study. For multiple decades, researchers have been trying to find the ultimate universal model that will explain technology acceptance, intention to use that technology, and finally, actual usage. Davis (1989) paper was a milestone as technology acceptance models go and explained quite a bit—with a particular population, particular technology, and specific demographic and environmental conditions. Follow-on studies continued to evolve the TAM by adding additional constructs that seemed to explain variance with other populations as demonstrated by the 63 constructs listed in Appendix C. The literature review delved into some of these diverse models used in the search for the ultimate ideal universal model. Unfortunately, populations, technologies, environments, past experience, health conditions, psychological factors, and a multitude of other factors vary when adapting a model to a particular population—like the AVC population.

The TAM framework provided a starting point to study the AVC population using three main constructs—*perceived ease of use*, *perceived usefulness*, and *intent to use*. Twenty-four Likert questions were gleaned from a literature review that examined many different technology and health belief acceptance/adoption models. To keep the questionnaire concise, sub-construct based questions (*effort efficacy, self-efficacy, attitude, visibility,* *performance expectancy, health beliefs, social norms/influence, and response cost*) were used based upon four key studies that combined mobile device technology with health beliefs and also primarily based upon the TAM framework. However, conciseness limited the number of questions that could be asked relative to each sub-construct, prevented confirmatory factor analysis from being used and resulted in using exploratory factor analysis to test construct validity. Rather than two constructs, *perceived ease of use* and *perceived usefulness*, emerging from the AVC data collected, five factors were extracted using exploratory factor analysis (which may have been a reflection of the eight sub-constructs used in creating the questionnaire), and five similar but still different group of factors using the Likert percent agree sort (see Table 22). The EFA five factors extracted explained 75% of the variance of the responses to the 23 questions. Additional factors are needed to explain the remaining 25% variation in the response data.

Potentially, there is a different or more ideal model than the TAM that more accurately represents the AVC response data to the 23 Likert questions. Although eight sub-constructs were used in the TAM framework (e.g., *effort expectancy*, *self-efficacy*), five primary factors emerged as shown previously in Table 22 and also in Table 35 to explain the data variance. The EFA Factor 1 (covering questions related to *effort expectancy*, *attitude*, *visibility*, and *performance expectancy*) spanned both *perceived ease of use* and *perceived usefulness* constructs. The Likert sort split EFA Factor 1 into two factors (*concept* and *how operationally* telemedicine improves care) which correspond to *attitude* and *performance expectancy* in the TAM. The EFA Factor 4 spanned *perceived ease of use* and *perceived usefulness* and corresponded to TAM constructs *self-efficacy*, *visibility*, and *response cost*. EFA Factor 5 corresponded to Q4 and Q5 (or *self-efficacy* only). The Likert agree sort approach grouped EFA’s Factor 4 and 5 into a single factor, *hands-on/ability* (or *performance expectancy*).

Table 35

TAM Sub-Constructs, Exploratory Factor Analysis, and Likert Percent Agree Sorted Factors

Q#	Question	Technology Acceptance Model		EFA Extracted Factor	Likert % Agree Sort
Q1	It Will Make Caregiving Easier (Q1)	Effort Expect.		Factor 1	How Op (Perf. Expect.)
Q2	It Will Make Interacting With Clinicians Easier (Q2)	Effort Expect.		Factor 1	How Op (Perf. Expect.)
Q3	It Will Provide Better Remote Support (Q3)	Effort Expect.		Factor 1	Concept (Attitude)
Q4	It Will Be Easy For Me To Use (Q4)	Self-Efficacy		Factor 5	HndsOnAbility (Self-Efficacy)
Q5	I Am Able To Use It (Q5)	Self-Efficacy		Factor 5	HndsOnAbility (Self-Efficacy)
Q6	I Have Videoconferencing Experience (Q6)	Self-Efficacy	Perceived Ease of Use (PEU)	Factor 4	HndsOnAbility (Self-Efficacy)
Q7	It is a Good Idea (Q7)	Attitude		Factor 1	Concept (Attitude)
Q8	It is Wise (Q8)	Attitude		Factor 1	Concept (Attitude)
Q9	I Can See the Benefits of Using It (Q9)	Visibility		Factor 1	Concept (Attitude)
Q10	I Can See the Value In Using It (Q10)	Visibility		Factor 1	Concept (Attitude)
Q11	I Will Need a Demo (Q11)	Visibility		Factor 4	HndsOnAbility (Self-Efficacy)
Q12	It Will Be Useful In Caregiving (Q12)	Perf. Expect.		Factor 1	How Op (Perf. Expect.)
Q13	Will Help Solve Problems More Quickly (Q13)	Perf. Expect.		Factor 1	How Op (Perf. Expect.)
Q14	Will Make Caregivers More Effective (Q14)	Perf. Expect.		Factor 1	How Op (Perf. Expect.)
Q15	It Will Take Time To Learn To Use It (Q15)	Resp. Cost		Factor 4	HndsOnAbility (Self-Efficacy)
Q16	It is Expensive To Use Telemedicine (Q16)	Resp. Cost		Factor 4	HndsOnAbility (Self-Efficacy)
Q17	I Will Need Support In Using It (Q17)	Resp. Cost		Factor 4	HndsOnAbility (Self-Efficacy)
Q18	People Important To Me Think I Should Use It (Q18)	Soc. Influ.		Factor 2	Soc. Influ.
Q19	People Whose Opinions I Respect Think I Should Use It (Q19)	Soc. Influ.	Perceived Usefulness (PU)	Factor 2	Soc. Influ.
Q20	People Who Influence Me Think I Should Use It (Q20)	Soc. Influ.		Factor 2	Soc. Influ.
Q21	People Who Use Ventilators Are Susceptible to Medical Emergencies (e.g. Infections) (Q21)	Health Beliefs		Factor 3	Health Beliefs
Q22	People Who Use Ventilators Are Vulnerable to Equipment Failures (Q22)	Health Beliefs		Factor 3	Health Beliefs
Q23	People Who Use Ventilators Are At Risk of Serious Issues That Require Immediate Attention (Q23)	Health Beliefs		Factor 3	Health Beliefs

Uncovering the perfect technology acceptance model to explain the AVC *intent to use* is a complex problem. To get adequate signal strength to perform structural equation modeling would require an additional 150+ questionnaire responses. Additionally, more sub-constructs are probably required to fully explain *intent to use* and will be discussed later in the section Further Research.

Practical Implications

Many previously unknown variables about the Assisted Ventilation Clinic patient and caregiver population have been explored by this study. Among the respondents, there is significant interest in using mobile device videoconferencing for remote mechanically-ventilated patient management. Although many variables such as cost, experience, and training must be must be managed, the response mean to Likert question 24 (“If you own/have access, or did own/have access—would you use mobile device videoconferencing for mechanically-ventilated patient management?”) with a mean response of 4.06 indicates a strong *intent to use* telemedicine. The research showed that the Assisted Ventilation Clinic patient/caregiver population is well equipped with mobile devices, with connectivity in the patient’s home, and with the majority having experience using those devices.

Although no single variable analyzed so far in this study was a sole indicator of *intent to use*, the overall *perceived usefulness* and *ease of use* in using telemedicine is a strong indicator of patients’ and caregivers’ *intent to use*. Results indicate that no single demographic variable is significantly correlated with *intent to use* telemedicine. This suggests that there may be number of complex interacting variables that ultimately determine a respondent’s *intent to use* mobile devices for ventilated patient management. Exploratory factor analysis extracted five latent variables that utilize Q1 through Q23 to explain 75% of the variance in the variables (rather than two in the TAM model). This also suggests a more complex model may exist to explain the remaining variance. Although structural equation modeling could account for the remaining unexplained variance, a minimum of 300 total respondents would be required to generate adequate signal strength between the variables for this type of variance analysis (see Appendix K).

Limitations of the Study

One of the limitations of the study is the inability to fully assess the entire Assisted Ventilation Clinic population. When patients and caregivers are asked to complete the questionnaire, many patients were too sick to answer for themselves and many caregivers are performing hands on care much like an intensive care unit, making it difficult to get responses. There is a broad range of mental and physical ability of the patients to use mobile devices—or to even understand and complete the questionnaire. Of the estimated 670 patients supported by the Assisted Ventilation Clinic, it was unclear how many are simply physically or mentally unable to complete the questionnaire. Although an attempt was made to collect basic questions from non-responders (e.g., mobile device *own/access* and *intent to use*) many declined to complete the questionnaire for various reasons. Some comments and reasons included (a) "I only want to talk to my doctor face-to-face"; (b) "When my life is on the line, I'll come to the Assisted Ventilation Clinic. I'm not depending on a mobile device to keep me alive"; (c) "The patient care is just too complex to do it by phone" (from a professional caregiver); and (d) Given the general intensity in the clinic that life critical activities are going on resulted in completing a questionnaire being very low on their list of priorities.

Of the 35 respondents not completing the questionnaire, 13 were patients simply unable to communicate. Another 11 had access to mobile devices—six (54%) agreed to *intent to use*, while five (46%) disagreed, saying they had no *intent to use.* Of the 10 non-respondents with no mobile devices (some had flip-phones), 100% had no *intent to use* (they disagreed without hearing a full explanation of telemedicine). One caregiver simply needed to leave immediately. Data collection constraints included only being able to collect data on Tuesday and Wednesday based upon patients visiting the Assisted Ventilation Clinic on those days. Patient Assisted Ventilation Clinic visits are scheduled randomly throughout the year for the most part—the random sampling of the population depended upon office visits being scheduled randomly. The challenge of preventing bias in the data collection was to collect some amount of data from patients and caregivers even if they declined to complete the questionnaire. There was concern that respondents who either own or have access to mobile devices might have been more biased toward *intent to use,* while non-responders who don't own or have access to mobile devices may be more biased toward intending not to use them. However, the results based upon the 153 questionnaire respondents did not show bias toward intending to use telemedicine as evidence indicated owning or having access did not correlate with a greater *intent to use*.

Recommendations

Based upon the patient and caregiver responses to question 24 (Q24), "Do you plan on using mobile device videoconferencing for remote mechanically-ventilated patient management?" 80% agree to use it, 13% are neutral, and seven percent disagree and don't plan on using the technology. From a conceptual point of view, 90% of the respondents think it is wise, smart, and the benefits are obvious. From a practical point of view, most respondents agree in the high 80% range with it making caregiving easier, helping to solve problems, and making interactions with clinicians easier. Yet there are still 20% that are not convinced to use it. There are barriers and factors that must be identified and overcome for this group to fully accept the mobile device videoconferencing solution.

There are actually three layers of technology that impact mobile device videoconferencing acceptance. The first includes mobile devices, downloading applications, videoconferencing, and using them to solve medical and equipment problems in the home. A second technology factor is the ventilator—if users have mastered the ventilator, they may not feel a need for other mobile device support. On the other hand, if they are unsure of their abilities to manage a ventilator, they may be motivated to use mobile devices. A third technology that must be accepted for mobile device videoconferencing is using the online patient portal to access the video telemedicine link.

A starting point for understanding the sub-populations in the overall AVC patient and caregiver population is to divide them into different groups with unique characteristics according to Roger's adoption/innovation curve (Rogers, 2003). Innovation adopters are divided into five groups based upon characteristics listed below those categories: innovators, early adopters, early majority, late majority, and laggards (Figure 29). For example, patients and caregivers in the innovation group were quick to ask if they could be in a pilot test. They are ready to adopt now. At the other extreme are the laggards—they are easily identified by comments such as "It will be too hard to learn," or "I only want face-to-face visits with my doctors," or there are some that are simply physically or mentally unable to perform the required tasks for videoconferencing.

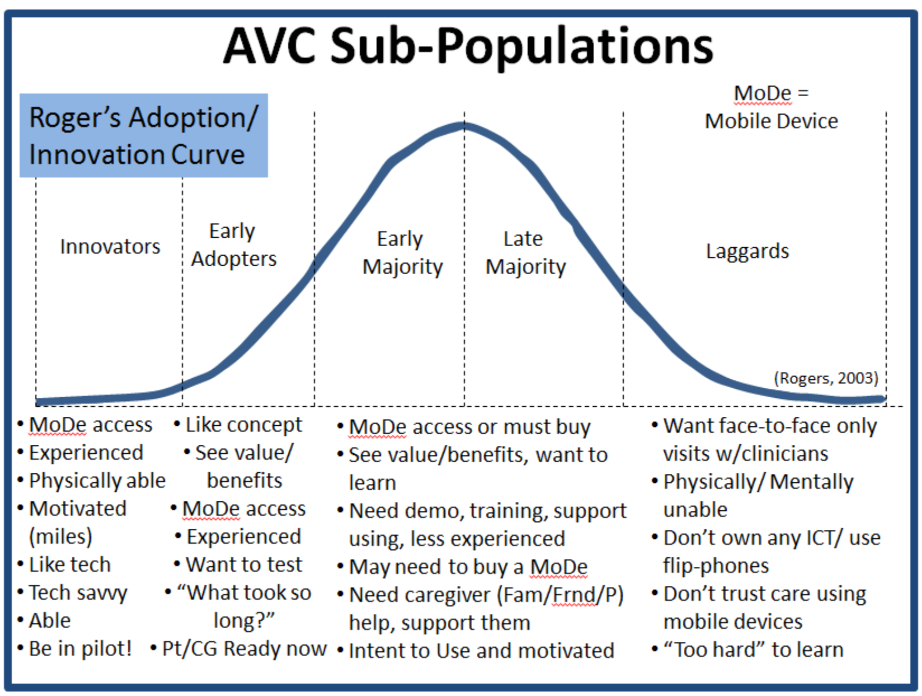


Figure 29. Identifying characteristics of AVC sub-populations using Roger's adoption curve.

Although not exact, Figure 30 presents qualitative factors that impact a user's probability of adopting mobile device videoconferencing. The five adoption groups that Rogers identifies are shown from innovators to laggards. There are several positive and negative characteristics listed along the left column—high agreement with positive factors and low agreement with negative factors lands that person in the innovator group. Likewise, disagreement with positive factors and high agreement with negative factors lands a person in the laggard group. The stop light green, yellow, and red, of course, indicate the patient's or caregiver's acceptance position, green equals ready to go, yellow indicates some reservations, and red indicates a barrier to adoption. Clinicians familiar with patients and caregivers may have more insight into which of their patients and associated caregivers would make the best candidates for using this service even though they may have no intent to use the service.

What are some of the implications for clinical administrators based upon results of this study? For one, simply supplying a video link to connect the patient or caregiver at home with the clinician (MD, NP, RT, RN, or others) in the AVC may not be enough. Although the response to mobile device videoconferencing was very positive as a concept, practically performing the tasks associated with turning off alarms, adjusting settings, or finding a tube leak while the patient can't breathe can be challenging and unnerving. For many, having some simulated training before the actual emergency event occurs may enable them to perform particular tasks when they need is the greatest. At this time, only scheduled telemedicine visits are allowed but urgent visits may be supported in the future. Competing telemedicine services offer immediate visits with patients and it may be standard in the future.

Looking more broadly across the various departments of Michigan Medicine, there is a spectrum of different tasks that are performed in different settings. Some are time critical, some are not. Acne patients sending a store-and-forward image of their face to help a dermatologist determine that the medication is adequate is very different than turning off an alarm or correcting a ventilator problem (although urgent or emergent telemedicine visits are not supported at this time). Simple factors like lighting or color can undermine a videoconferencing session or present an inaccurate picture. There should be some standards and best practices for making the videoconferencing session as successful as possible.

Now that MiChart has videoconferencing capability built in, it will eventually be available across all departments of the health system. There is a basic level of training—more than the equipment works—that would be valuable for all telemedicine users (patients and caregivers at home as well as clinicians in Michigan Medicine). Providing a call in test drive connection would allow people to develop a level of comfort with the technology, performing some basic operations, and test in their home environment to make sure an optimum environment is created. Background noise and light is minimized, verification is confirmed that they can perform the basic manipulations required, and any department specific requirements are in place. For example, fluorescent lighting will be different than incandescent lighting. For people that are new to mobile devices or are unsure of their abilities to use the service, this will reassure them that they are able. General videos that apply to all departments and telemedicine in general should be available online, while unique videos tailored to particular departments should also be available.

For the AVC in particular, a great amount of time is spent in the waiting or in the clinic room waiting for their turn with a clinician. For patients and caregivers that have expressed interest in using mobile device videoconferencing, or for those patient and caregivers targeted by AVC clinicians as prime candidates for using the service, they could watch a video detailing all the tasks they will need to perform at home. If there were a central test service for telemedicine, patients and caregivers can test their mobile devices, download any required applications, leave the AVC knowing how to access the patient portal, enter all required information, and be able initiate their telemedicine visit. Currently, Vidyo is the videoconferencing application integrated into the MiChart/EPIC medical records system which may be used—possibly they could interact with a Vidyo test site to ensure they are operational. Support for patient portal access should already be in place since this is a pre-requisite for accessing the MiChart telemedicine link.

Innovators, early adopters, and many early majority adopters should have the tools and experience to use mobile device videoconferencing immediately. For late majority and laggards, more extensive coaching may be required to help them overcome barriers such as only being comfortable with face-to-face visits, not trusting or accepting technology, or believing it is too hard to learn. For those with flip-phones or for those physically or mentally unable to perform the tasks required for mobile device videoconferencing, they may be totally dependent upon a caregiver that is an innovator, early adopter, or early majority to perform the videoconferencing. Those in the late majority may need special training or purchase equipment to be able to perform remote mechanically-ventilated patient management using mobile device videoconferencing.

AVC Sub-Population Characteristics

AVC Sub-Populations of Telemedicine Acceptance						
	Factor to Consider	Innovators	Early Adopters	Early Majority	Late Majority	Laggards
Positives	Mobile Device Access	High	High	Med	Med	Low
	Cellular/WiFi/Internet	High	High	High	Med	Low
	MiChart Patient Portal Access	High	High	Med	Med	Low
	See the Value, Like the Concept	High	High	High	Med	Low
	Enthusiasm Level	High	High	Med	Low	Low
	Experience Videoconferencing	High	High	Med	Low	Low
	Experience Downloading Apps	High	High	Med	Low	Low
	Want to Be In a Pilot Study	High	Med	Low	Low	Low
	Technology Savvy	High	Med	Med	Low	Low
	Physically Able to Make Call	High	Med	Med	Low	Low
	Mentally Able to Make Call	High	Med	Med	Low	Low
	Motivating Factors (distance, severity, inexperience)	High	Med	Med	Med	Low
	Has Caregiver Buy-In and Support	High	High	Med	Med	Low
Negatives	Need for Training and Support	Low	Med	Med	High	High
	Insist on Face-to-Face Only Visits	Low	Low	Low	Med	High
	Don't Trust Technology	Low	Low	Low	Med	High
	"Too Hard To Learn", Afraid to Try	Low	Low	Low	Med	High
	Own Flip Phone	Low	Low	Med	Med	High
	Need Demo, Support, Training	Low	Low	Med	High	High

Figure 30. Levels of videoconferencing adoption for mobile device patient management

Further Research

To quote both Gupta and Gupta (2011, p. 179) and Bhatta (2013, p. 38), "most research uncovers more questions than answers," which is also true for this study. In addition to the six suggestions for further research outlined at the end of this section, there are some other areas of inquiry that would be valuable to consider. Information security and privacy, choosing models and variables, and actual usage are additional areas that would benefit from further research. The heart of this study revolved around using mobile device videoconferencing to securely modify settings or the configuration of mechanical ventilators in the patient's home. These actions must be measured against confidentiality, integrity, and availability, three key cornerstones of information security. Dr. Avi Rubin, a computer science professor and security expert at John's Hopkins University, states that "all your devices are hackable" in his 2011 TedTalk (Rubin, 2011). Specifically, any device that relies on software and has connectivity can be hacked. Devices that meet this requirement include both mobile devices, laptops, desktops, ventilators, and other respiratory devices. Trilogy and Astral ventilators have connectivity capability (Ethernet or WiFi), allowing ventilator data to be downloaded from the ventilator to the cloud for viewing by doctors or medical device support personnel. Astral clearly states that remotely changing configuration settings of their ventilator in life-support situations is not allowed. Secure ventilator setting updates or reconfiguration cannot be guaranteed in life critical applications. Critical elements that must be guaranteed when using mobile devices in remote mechanically-ventilated patient management include: authentication (identifying the users and processes are recognized and correct), confidentiality (only two people communicating—if third party interferes, it is known), integrity (the data is accurate and uncompromised—real time direction and confirmation of correct actions is mandatory), and availability (data is available real-time—however, denial of service is a possibility). An analysis or research comparing mobile device videoconferencing versus remote ventilator access would be a valuable study to measure information assurance and hacking vulnerability.

Using the TAM framework provided a starting point for identifying measurement items for the questionnaire. Efforts to keep the questionnaire concise and short also limited the number of sub-constructs that were used to collect Likert data. Other variables that may have an impact on *intent to use* include: the *socio-economic* status of respondents, their *education level* and *attitudes* toward the technology, *computer self-efficacy*, and *self-efficacy of applications*. Although available references (Taylor & Todd, 1995; Venkatesh & Davis, 2000; and Venkatesh et al., 2003) provide evidence that there is a relationship between behavioral intention and actual usage, additional research would help identify the AVC population relationship between *intent to use* and *actual usage*. One factor modifying of these variables is the fact that many of the respondents are already familiar with videoconferencing and downloading applications and are already current users. Ownership and access (*own/access*) to mobile devices was not clearly delineated between patient and caregiver. Ownership is not the same as access. The caregiver may own the device and be very comfortable using it while the patient has access but does not have hands-on familiarity with the mobile device. Although the researcher was present with the respondents as they completed the questionnaire, it was not a qualitative observational study.

Actually performing a qualitative study to observe, log, sort, group, and identify variables that impact respondents *intent to use* would be a valuable study. In addition to other technical and clinical variables (lighting, color, etc.) that must be discovered and analyzed, a qualitative study would also allow patients and caregivers to move beyond *intent to use* to *actual usage.* In an observational qualitative study, actual hands-on usage of mobile device remote guidance could be observed with patients and caregivers actually using mobile devices, a ventilator, and a remote guidance person in another part of the clinic. In addition to training people as they pass through the clinic during regular visits, barriers and problems could be identified and strategies for overcoming them could be developed, and even tested real-time. In particular, one variable that was not measured was use or access to the MiChart patient portal. AVC patients and caregivers will not be using videoconferencing unless they are comfortable using the patient portal—the patient portal represents another layer of technology acceptance in order to use mobile device videoconferencing.

Another critical area that would provide valuable data would be a cost analysis of mobile device videoconferencing versus usual care. Billing is essential for hospitals to implement telemedicine services, and AVC cost analysis research could provide valuable information for insurers. An example is transportation from the patient's home to the AVC clinic (or a nearby emergency department). A call to a regional ambulance service revealed a range of *private* pay costs for transporting people in a wheelchair with only a driver and no other personnel, up to the full service intensive care transport. For transporting a person in a wheelchair (no oxygen, no ventilator, and only the driver present), the cost is a $443 base charge each way plus $13.50 per mile. If an advanced life support person is also assisting and performing EKG monitoring, the base fee increases to $742 each way. If the ambulance service provides the ventilator, the base cost is $1,195. These are private pay estimates and insurance company agreements impact actual costs. However, given that some of the AVC patients travel over 300 miles to the AVC, and the average distance to the AVC is around 60 miles, the cost for transport alone can be in the thousands of dollars for a visit to the AVC. Wheelchair only transport alone using the average AVC of 60 miles each way results in transport charges of over $2,500. Using ICU level transport and traveling a distance of 300 miles each way results in a cost of over $10,000. Clearly, telemedicine and remote ventilated patient management using mobile devices can have a significant impact on reducing healthcare costs if a trip to the clinic can be avoided. Transport charges can be obtained and verified by calling any local ambulance service, so no specific reference is provided in this document.

This study focused on understanding the Assisted Ventilation Clinic patient and caregiver population's *intent to use* mobile technologies for remote ventilated patient management. It provided an excellent foundation for understanding patient and caregiver acceptance of using the technology and gaining insight into the owned/accessible infrastructure they provide for telemedicine use at home. However, there are other subsequent research studies that would provide valuable evidence as telemedicine is implemented in the Assisted Ventilation Clinic and across the University of Michigan health system, now referred to as Michigan Medicine.

Six additional research topics are listed below:

1. Collect more data from the Assisted Ventilation Clinic population (at least 300 total completed questionnaires) and combine with other studies of different patient population in Michigan Medicine to more fully understand the differences in patient populations served by different specialties. Creation of a short video would be helpful in educating patients and caregivers in the use of mobile devices in remote ventilated patient management.

2. Survey the thousands of physicians and clinicians in the Michigan Medicine organization to determine their *intent to use* telemedicine. Understanding the current physician workflow where patient visits must be scheduled 3 months in advance may leave little room for telemedicine visits without significant changes in workflow. However, the alternative is also possible - telemedicine visits could be seamlessly integrated into physicians' daily clinical workflows. Physician and clinician buy-in is critical for telemedicine success and further research would reveal latent barriers.

3. Two research studies are shown in Figure 31 are subsequent to this descriptive study, a qualitative study and an experimental study. The qualitative study is based upon action research and the grounded theory research model (refer to Figure 32). Its goals are to

discover independent and dependent variables, parameters, and factors associated with remotely managing mechanically-ventilated patients using mobile devices.

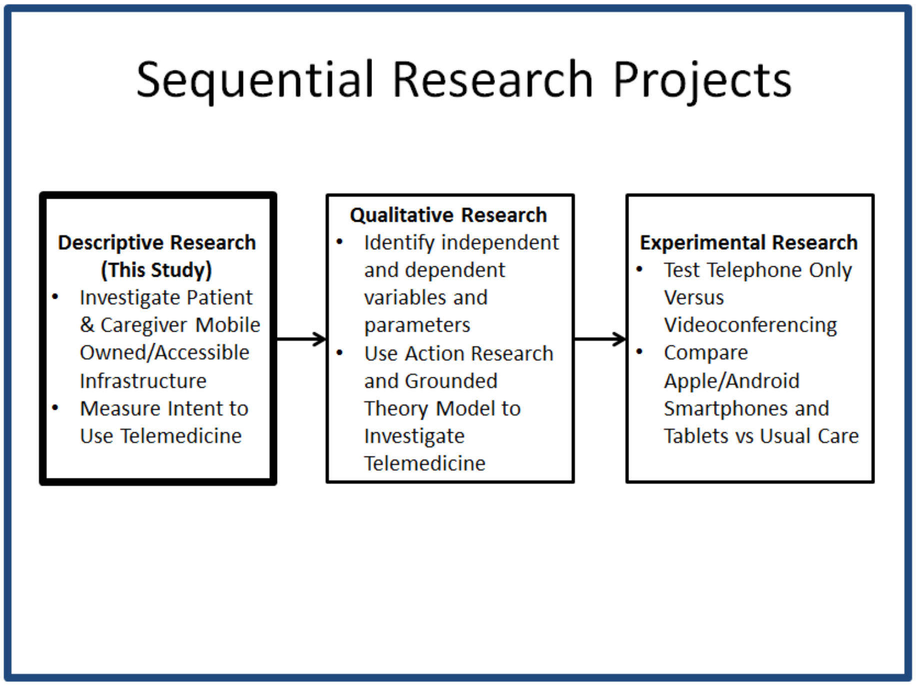


Figure 31. Two subsequent research projects to this study—qualitative and experimental

A qualitative study would be valuable in understanding the strengths and weaknesses of various telemedicine technologies used and also the accuracy of various parameters that are essential for care and diagnosis using telemedicine (refer to Figure 32). This diagram outlines a process that can be used to optimize a videoconferencing (VC) environment and also for evaluating new telemedicine technologies and peripherals (e.g., high resolution cameras, EKG systems, digital stethoscopes, ultrasound devices …)

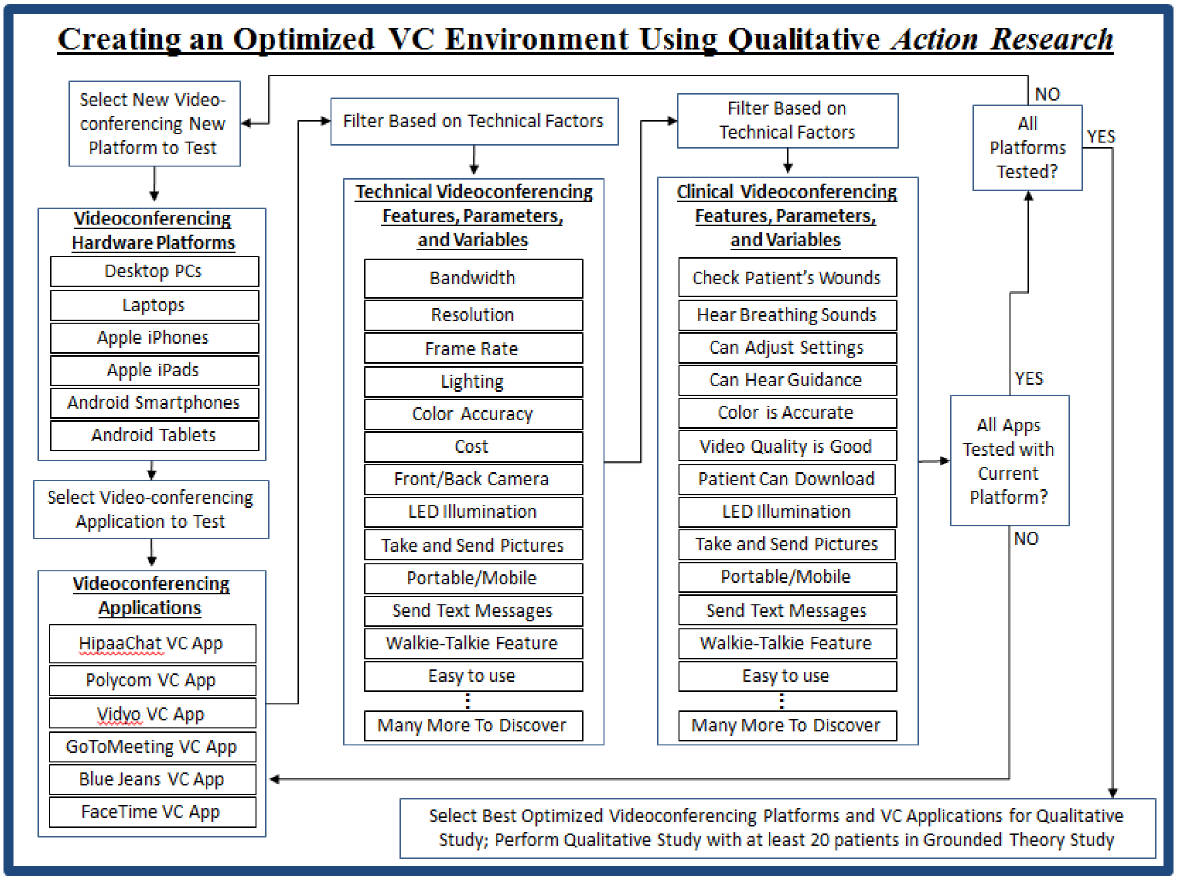


Figure 32. Qualitative action/grounded theory research of technology and parameters.

4. An experimental study would be valuable in comparing the differences between the current standard of remote care using telephone-only support versus using mobile device videoconferencing. Comparing a control group with other groups using Apple, Android, or other mobile devices and videoconferencing could quantitatively allow measurement of the differences between telephone-only support versus videoconferencing.

A case-controlled, quasi-experimental study (refer to Figure 33) will integrate results from this descriptive study and the qualitative study into its framework. The experimental study compares the effectiveness of telephone-only versus videoconferencing in remote ventilated patient management and builds upon the *intent to use* data gathered in this study. The experimental participants can be divided into usual care (telephone audio-only), Apple iPhone, Apple iPad, Android smartphone, and Android tablet groups. Measured outcomes could include time to resolve problems, number of RT visits, emergency department visits, Assisted Ventilation Clinic visits, hospitalization, and mortality (refer to Figure 34).

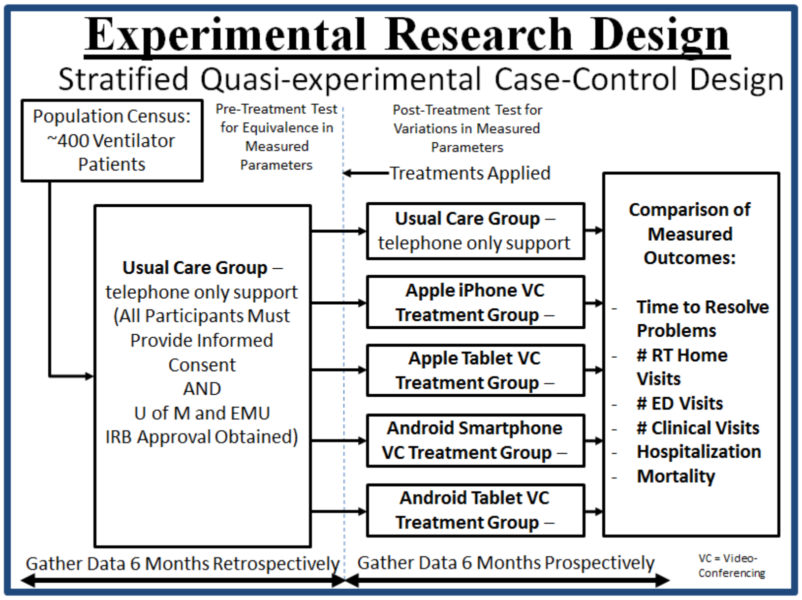


Figure 33. Design structure of a subsequent experimental research study.

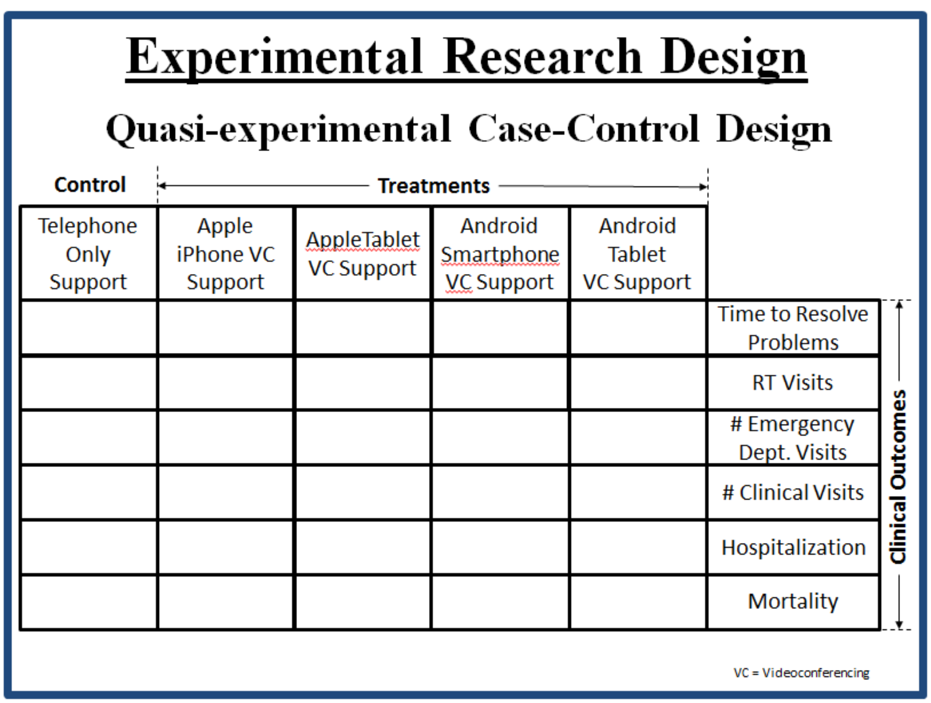


Figure 34. Quasi-experimental case-control design analysis matrix

5. The Zero Knowledge Test, discussed earlier, was introduced as a way to manage ventilators remotely using the concept of remote expert collaborative guidance (RECG). Using RECG has the potential to allow experts in one part of the world to guide inexperienced caregivers through complex procedures or triage in remote areas such as those experiencing natural disasters, isolated third world countries, the battle field, or even guiding someone doing CPR during a 911 call. The pervasiveness of mobile devices throughout the world may provide a global infrastructure for this type of remote care and further research in RECG would be valuable.

6. The University of Michigan *Health Research* (2016) website was investigated as a tool for data collection. Approval was granted for a link to the questionnaire located on the website that would give access to 26,000 people interested in participating in research. However, the decision was made to not use the website because people outside the Assisted Ventilation Clinic may respond and the population under study was the Assisted Ventilation Clinic patients and caregivers. A future study could be conducted using Health Research (2016) website for data collection from a much larger population including patients and caregivers outside the Assisted Ventilation Clinic.

References

AVC. (2016). Michigan Medicine Adult Assisted Ventilation Clinic. Retrieved on March 15, 2016 from http://www.uofmhealth.org/conditions-treatments/pulmonary/assisted-ventilation-clinic

ACO. (2015). Fast facts: POM ACO. Retrieved on December 21, 2015 from http://www.uofmhealth.org/fast-facts-pom-aco

Ahadzadeh, A. S., Sharif, S. P., Ong, F. S., & Khong, K. W. (2015). Integrating health belief model and technology acceptance model: An investigation of health-related internet use. *Journal of Medical Internet Research, 17*(2), e45.

Ajzen, I. (1985). From intentions to actions: A theory of planned behavior. In J. Kuhl & J. Beckmann (Eds.), *Action Control: From Cognition to Behavior* (pp. 11-39). Berlin Heidelberg: Springer.

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes, 50*(2), 179-211.

Ajzen, I., & Fishbein, M. (1977). Attitude-behavior relations: A theoretical analysis and review of empirical research. *Psychological Bulletin, 84*(5), 888.

Allen, R. (2017). Exploratory factor analysis on SPSS. Adapted from YouTube video on February 11, 2017 from https://www.youtube.com/watch?v=-6tw7ebr860

Andersen, D., Popescu, V., Cabrera, M. E., Shanghavi, A., Gomez, G., Marley, S., ... & Wachs, J. P. (2016). Medical telementoring using an augmented reality transparent display. *Surgery, 159*(6), 1646-1653.

Aungst, T. D., & Lewis, T. L. (2015). Potential uses of wearable technology in medicine: lessons learnt from Google Glass. *International Journal of Clinical Practice*, *69*(10), 1179-1183.

AVC1. (2016). Assisted Ventilation Clinic: Comprehensive Ventilation Support in One Location. Retrieved March 28, 2016 from http://www.uofmhealth.org/conditions-treatments/pulmonary/assisted-ventilation-clinic

AVC2. (2016). Assisted Ventilation Clinic, UMHS Pulmonary and Critical Care Division of the Internal Medicine Department. Retrieved on March 28, 2016 from https://medicine.umich.edu/dept/pulmonary-critical-care-medicine/assisted-ventilation-clinic-0

Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavioral change. *Psychological Review*, *84*(2), 191.

Bashshur, R., Shannon, G., Krupinski, E., & Grigsby, J. (2011). The taxonomy of telemedicine. *Telemedicine and e-Health*, *17*(6), 484-494.

Bashshur, R. L., Shannon, G. W., Smith, B. R., Alverson, D. C., Antoniotti, N., Barsan, W. G., ... & Ferguson, S. (2014). The empirical foundations of telemedicine interventions for chronic disease management. *Telemedicine and e-Health, 20*(9), 769-800.

Bashshur, R. L., Shannon, G. W., Smith, B. R., & Woodward, M. A. (2015). The empirical evidence for the telemedicine intervention in diabetes management. *Telemedicine and e-Health*, *21*(5), 321-354.

Becker, G. (1974). A theory of social interactions. *Journal of Political Economy*, *82*(6), 1063-1093.

Bell, R. C., Yager, P. H., Clark, M. E., Roumiantsev, S., Venancio, H. L., Chipman, D. W., ... & Noviski, N. N. (2016). Telemedicine versus face-to-face evaluations by respiratory therapists of mechanically-ventilated neonates and children: A pilot study. *Respiratory Care, 61*(2), 149-154.

Bishop, P. A., & Herron, R. L. (2015). Use and misuse of the Likert item responses and other ordinal measures. *International Journal of Exercise Science*, *8*(3), 10.

Bitly (2016). URL Shortener – Bit.ly webite link to Qualtrics questionnaire. Found at **http://bit.ly/2hq1BQf** .

Boroughs, D., & Dougherty, J. A. (2012). Decreasing accidental mortality of ventilator-dependent children at home: a call to action. *Home Healthcare Now, 30*(2), 103-111.

Briggs, K. C. (1976). *Myers-Briggs type indicator*. Palo Alto, CA: Consulting Psychologists Press.

Budrionis, A., Augestad, K. M., Patel, H. R., & Bellika, J. G. (2013). An evaluation framework for defining the contributions of telestration in surgical telementoring. *Interactive Journal of Medical Research*, *2*(2).

Carifio, J., & Perla, R. (2008). Resolving the 50-year debate around using and misusing Likert scales. *Medical Education*, *42*(12), 1150-1152.

Casavant, D. W., McManus, M. L., Parsons, S. K., Zurakowski, D., & Graham, R. J. (2014). Trial of telemedicine for patients on home ventilator support: Feasibility, confidence in clinical management and use in medical decision-making. *Journal of Telemedicine and Telecare*, *20*(8), 441-449.

Cimperman, M., Brenčič, M. M., & Trkman, P. (2016). Analyzing older users' home telehealth services acceptance behavior—applying an Extended UTAUT model. *International Journal of Medical Informatics, 90*, 22-31.

Compeau, D. R., & Higgins, C. A. (1995). Computer self-efficacy: Development of a measure and initial test. *MIS Quarterly*, *13*(3), 189-211.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS quarterly*, *13*(3), 319-340.

Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1992). Extrinsic and intrinsic motivation to use computers in the workplace. *Journal of Applied Social Psychology*, *22*(14), 1111-1132.

Deenen, J. C., Horlings, C. G., Verschuuren, J. J., Verbeek, A. L., & van Engelen, B. G. (2015). The epidemiology of neuromuscular disorders: A comprehensive overview of the literature. *Journal of Neuromuscular Diseases*, *2*(1), 73-85.

Dermoscope. (2014). Dermoscope Image. Retrieved 11/18/2014 from http://mobihealthnews.com/34985/idoc24-study-finds-smartphone-enabled-dermatology-screening-more-efficient-for-referrals/

DeVivo, M., Chen, Y., Mennemeyer, S., & Deutsch, A. (2011). Costs of care following spinal cord injury. *Topics in Spinal Cord Injury Rehabilitation*, *16*(4), 1-9.

DigStethoscope. (2014). Digital Stethoscope. Retrieved 11/18/2014 from http://www.news.com.au/technology/digital-stethoscope-detects-pneumonia-in-the-palm-of-your-hand/story-e6frfro0-1226344970563

Durbin, C.G. (2010). Tracheostomy: Why, when, and how? *Respiratory Care, 55*, 1056-68.

ECG. (2014). Smartphone ECG. Retrieved 11/18/2014 from http://www.gizmag.com/app-to-view-electrocardiograms-on-smartphones/16664/

Everbridge (2015). Manufacturer of the *HipaaChat* application. Information located at www.everbridge.com.

Factor. (2015). Factor analysis. University of Alabama website. Retrieved on December 17, 2015 from http://www.bama.ua.edu/~jcsenkbeil/gy523/Factor%20Analysis.pdf

Faqih, K. M., & Jaradat, M. I. R. M. (2015). Assessing the moderating effect of gender differences and individualism-collectivism at individual-level on the adoption of mobile commerce technology: TAM3 perspective. *Journal of Retailing and Consumer Services*, *22*, 37-52.

Fishbein, M., & Ajzen, I. (1977). Belief attitude, intention and behavior: An introduction to theory and research. *Philosophy and Rhetoric, 10*(2), 130-132.

Fredriksson, J., Groth, K., Rasanen, M., Bergius, H., & Rylander, E. (2014, May). Effects of mobile video-mediated communication for health care professionals in advanced home care of children. In Computer-Based Medical Systems (CBMS), 2014 IEEE 27th International Symposium on (pp. 363-368). IEEE.

Gammon, D., Johannessen, L. K., Sørensen, T., Wynn, R., & Whitten, P. (2008). An overview and analysis of theories employed in telemedicine studies-A field in search of an identity. *Methods of information in medicine, 47*(3), 260-269.

Gao, Y., Li, H., & Luo, Y. (2015). An empirical study of wearable technology acceptance in healthcare. *Industrial Management & Data Systems,115*(9), 1704-1723.

Gilchrist, J. M. (2002, June). Overview of neuromuscular disorders affecting respiratory function. In *Seminars in respiratory and critical care medicine, 23*(3), 191-200.

Glanz, K., Rimer, B. K., & Viswanath, K. (Eds.). (2008). *Health behavior and health education: theory, research, and practice*. John Wiley & Sons.

Goran, S. F. (2010). A second set of eyes: an introduction to tele-ICU.*Critical Care Nurse*, *30*(4), 46-55.

Grace-Martin, K. (2016). Can Likert scale data ever be continuous? Retrieved on June 12, 2016 from http://www.theanalysisfactor.com/can-likert-scale-data-ever-be-continuous/ .

Gupta, M., & Gupta, D. (2011). Research methodology. New Delhi: PHI Learning Private.

Hashimoto, D. A., Phitayakorn, R., Fernandez-del Castillo, C., & Meireles, O. (2016). A blinded assessment of video quality in wearable technology for telementoring in open surgery: the Google Glass experience. *Surgical endoscopy*, *30*(1), 372-378.

Hawking (2016). Stephen Hawking Official Website. Retrieved March 15, 2016 from http://www.hawking.org.uk/

Hazenberg, A., Kerstjens, H. A. M., Prins, S. C. L., Vermeulen, K. M., & Wijkstra, P. J. (2014). Initiation of home mechanical ventilation at home: A randomised controlled trial of efficacy, feasibility and costs. *Respiratory medicine*, *108*(9), 1387-1395.

Healthcare IT. (2015). How many health apps actually matter? Retrieved on March 20, 2016 from http://www.healthcareitnews.com/news/how-many-health-apps-actually-matter

Health Research. (2016). University of Michigan Health Research website. Available at www.umhealthresearch.org .

HIPAA. (2013). 45 CFR Parts 160 and 164, Federal Register / Vol. 78, No. 17 / Friday, January 25, 2013 / Rules and Regulations. Retrieved 11/18/2014 from http://www.gpo.gov/fdsys/pkg/FR-2013-01-25/pdf/2013-01073.pdf

HipaaChat. (2014). Images retrieved on 11/18/2014 from http://www.hipaachat.com/ and from http://www.apps555.com/apps/HipaaChat-com-tapestrytelemed-hipaachat-android-v3.html and from https://itunes.apple.com/us/app/hipaachat-lite/id642738088?mt=8

Hochbaum, G. M. (1958). Public participation in medical screening programs: A socio-psychological study. US Department of Health, Education, and Welfare, Public Health Service, Bureau of State Services, Division of Special Health Services, Tuberculosis Program.

IMS. (2016). IMS Health Report – Patient Adoption of mHealth. Retrieved on May 3, 2016 from www.imshealth.com

Irfan, M., Selim, B., Rabinstein, A. A., & Louis, E. K. S. (2015). Neuromuscular Disorders and Sleep in Critically Ill Patients. *Critical care clinics*, *31*(3), 533-550.

Istepanian, R. S., & Lacal, J. C. (2003, September). Emerging mobile communication technologies for health: some imperative notes on m-health. In Engineering in Medicine and Biology Society, 2003. Proceedings of the 25th Annual International Conference of the IEEE (Vol. 2, pp. 1414-1416). IEEE.

HealthResearch. (2016). University of Michigan Health Research webpage. Found at **www.umhealthresearch.org** .

Holden, R. J., & Karsh, B. T. (2010). The technology acceptance model: its past and its future in health care. *Journal of biomedical informatics*, *43*(1), 159-172.

iTunes. (2016). iTunes preview > app store > medical. Retrieved on March 20, 2016 from https://itunes.apple.com/us/genre/ios-medical/id6020?mt=8

Jamieson, S. (2004). Likert scales: how to (ab) use them. *Medical education, 38*(12), 1217-1218.

Janz, N. K., & Becker, M. H. (1984). The health belief model: A decade later. *Health Education & Behavior, 11*(1), 1-47.

Jijiang, Y., Jianqiang, L., & Rodrigues, J. J. (2015). Guest editorial: Telecommunications for Remote Medicine. *Communications, China, 12*(4), iii-iv.

Jones, T. S., Burlew, C. C., Johnson, J. L., Jones, E., Kornblith, L. Z., Biffl, W. L., ... & Moore, E. E. (2015). Predictors of the necessity for early tracheostomy in patients with acute cervical spinal cord injury: a 15-year experience. *The American Journal of Surgery, 209*(2), 363-368.

Khatwa, U. A., & Dy, F. J. (2015). Pulmonary manifestations of neuromuscular diseases. *The Indian Journal of Pediatrics, 82*(9), 841-851.

Kim, H. W., Chan, H. C., & Gupta, S. (2007). Value-based adoption of mobile internet: an empirical investigation. *Decision Support Systems, 43*(1), 111-126.

Kim, C. H., & Kim, M. S. (2014). Ventilator use, respiratory problems, and caregiver well-being in korean patients with amyotrophic lateral sclerosis receiving home-based care. *Journal of Neuroscience Nursing, 46*(5), E25-E32.

Kim, C., Kang, B. S., Choi, H. J., Lim, T. H., Oh, J., & Chee, Y. (2015). Clinical application of real-time tele-ultrasonography in diagnosing pediatric acute appendicitis in the ED. *The American journal of emergency medicine,33*(10), 1354-1359.

Kim, J., & Park, H. A. (2012). Development of a Health Information Technology Acceptance Model Using Consumers' Health Behavior Intention. *Journal of Medical Internet Research, 14*(5), e133. http://doi.org/10.2196/jmir.2143

King, A. C. (2012). Long-term home mechanical ventilation in the United States. *Respiratory care*, *57*(6), 921-932.

Kirkpatrick, A. W., Tien, H., LaPorta, A. T., Lavell, K., Keillor, J., Beatty, H. E. W., ... & Ball, C. G. (2015). The marriage of surgical simulation and telementoring for damage-control surgical training of operational first responders: A pilot study. *The journal of trauma and acute care surgery*,*79*(5), 741.

Klein, M., Mogles, N., & van Wissen, A. (2013). An intelligent coaching system for therapy adherence. *Pervasive Computing, IEEE*, *12*(3), 22-30.

Knapp, T. R. (1990). Treating ordinal scales as interval scales: an attempt to resolve the controversy. *Nursing research*, *39*(2), 121-123.

Kuo, D. Z., & Carroll, J. L. (2016). The Model of Care for the Ventilator-Dependent Child. In Caring for the Ventilator Dependent Child (pp. 121-143). Springer New York.

Larkindale, J., Yang, W., Hogan, P. F., Simon, C. J., Zhang, Y., Jain, A., ... & Cwik, V. A. (2014). Cost of illness for neuromuscular diseases in the United States. *Muscle & nerve*, *49*(3), 431-438.

Lee, Y., Kozar, K. A., & Larsen, K. R. (2003). The technology acceptance model: Past, present, and future. *Communications of the Association for information systems*, *12*(1), 50.

Leedy, P. D., & Ormrod, J. E. (2005). *Practical research: Planning and design.* New Jersey: Pearson Merrill Prentice Hall.

Li, H., Wu, J., Gao, Y., & Shi, Y. (2016). Examining individuals' adoption of healthcare wearable devices: An empirical study from privacy calculus perspective. *International Journal of Medical Informatics*, *88*, 8-17.

Lilly, C. M., McLaughlin, J. M., Zhao, H., Baker, S. P., Cody, S., & Irwin, R. S. (2014). A multicenter study of ICU telemedicine reengineering of adult critical care. *CHEST Journal*, *145*(3), 500-507.

Litwin, M. S. (1995). The Survey Kit. In A. G. Fink, *Vol. 7. How to measure survey reliability and validity.* California: Sage Publications.

MacDuff, A., & Grant, I. S. (2003). Critical care management of neuromuscular disease, including long-term ventilation. *Current opinion in critical care*, *9*(2), 106-112.

Madden, T. J., Ellen, P. S., & Ajzen, I. (1992). A comparison of the theory of planned behavior and the theory of reasoned action. *Personality and Social Psychology Bulletin*, *18*(1), 3-9.

Magsamen-Conrad, K., Upadhyaya, S., Joa, C. Y., & Dowd, J. (2015). Bridging the divide: Using UTAUT to predict multigenerational tablet adoption practices. *Computers in Human Behavior*, *50*, 186-196.

Maillet, É., Mathieu, L., & Sicotte, C. (2015). Modeling factors explaining the acceptance, actual use and satisfaction of nurses using an Electronic Patient Record in acute care settings: An extension of the UTAUT. *International Journal of Medical Informatics*, *84*(1), 36-47.

Marshall, S. J., & Biddle, S. J. (2001). The transtheoretical model of behavior change: A meta-analysis of applications to physical activity and exercise. *Annals of Behavioral Medicine*, *23*(4), 229-246.

McClenahan, C., Shevlin, M., Adamson, G., Bennett, C., & O'Neill, B. (2007). Testicular self-examination: A test of the health belief model and the theory of planned behaviour. *Health Education Research*, *22*(2), 272-284.

McHugh, M. L. (2009). The odds ratio: Calculation, usage, and interpretation. *Biochemia Medica*, *19*(2), 120-126.

MDA. (2016). Learn about muscular diseases. Muscular Dystrophy Association. Retrieved on March 26, 2016 from https://www.mda.org/disease/list

MDC. (2016). Comprehensive List of Neuromuscular Disorders Covered by Muscular Dystrophy Canada. Retrieved on March 26, 2016 from http://muscle.ca/wp-content/uploads/2012/10/Disorder_List_0903E.pdf

Medict. (2017). The Free Dictionary by Farlex. Retrieved on March 5, 2017 from http://medical-dictionary.thefreedictionary.com/quadriplegia

Melas, C. D., Zampetakis, L. A., Dimopoulou, A., & Moustakis, V. (2011). Modeling the acceptance of clinical information systems among hospital medical staff: An extended TAM model. *Journal of BiomedicalIinformatics, 44*(4), 553-564.

MenPhones. (2014). Men with Cell Phones. Retrieved 11/18/2014 from http://arch1design.com/blog/2009/10/cell-phone-vs-brain-cell-whos-the-loser/

Meter. (2015). Worldometers – current world population. Retrieved on March 14, 2016 from http://www.worldometers.info/world-population/#top20

Miller, N. E., & Dollard, J. (1941). *Social learning and imitation*. New Haven, CT, US: Yale University Press.

Miyasaka, K., Suzuki, Y., Sakai, H., & Kondo, Y. (1997). Interactive communication in high-technology home care: Videophones for pediatric ventilatory care. *Pediatrics*, *99*(1), 1-6; DOI: 10.1542/peds.99.1.e1.

Modern Healthcare. (2013). No longer a novelty, medical apps are increasingly valuable to clinicians and patients. Retrieved March 20, 2016 from http://www.modernhealthcare.com/article/20131214/MAGAZINE/312149983

Montano, D. E., Kasprzyk, D., Glanz, K., Rimer, B. K., & Viswanath, K. (2008). Theory of reasoned action, theory of planned behavior, and the integrated behavioral model. In K. Glanz, B. K. Rimer, & K. Viswanath (Eds.), *Health behavior: Theory, research and practice* (pp. 67-92). San Francisco, CA: John Wiley & Sons, Inc.

Moores, T. T. (2012). Towards an integrated model of IT acceptance in healthcare. *Decision Support Systems, 53*(3), 507-516.

Morin, M. J., Alvey, J., Murphy, N., & Glader, L. (2016). Models of Care for Children with Medical Complexity. In I. L. Rubin et al. (Eds.), *Health Care for People with Intellectual and Developmental Disabilities across the Lifespan* (pp. 195-208). Switzerland: Springer International Publishing.

Moumtzoglou, A. (2016). *M-Health Innovations for Patient-Centered Care* (p. 5). Hershey, PA: IGI Global. doi:10.4018/978-1-4666-9861-1

Murray, J. (2013). Likert data: What to use, parametric or non-parametric? *International Journal of Business and Social Science*, *4*(11), 258-264.

Nisha, N., Iqbal, M., Rifat, A., & Idrish, S. (2015). Mobile health services: A new paradigm for health care systems. *International Journal of Asian Business and Information Management (IJABIM), 6*(1), 1-17.

Norman, G. (2010). Likert scales, levels of measurement and the laws of statistics. *Advances in Health Sciences Education, 15*(5), 625-632.

Oh, H., Rizo, C., Enkin, M., & Jadad, A. (2005). What is eHealth?: A systematic review of published definitions. *World Hospital Health Services*, *41*(1), 32-40.

Otoscope. (2014). Otoscope. Retrieved 11/18/2014 from http://www.medgadget.com/2012/06/the-latest-on-cellscopes-smartphone-based-microscope-and-otoscope.html

Pagnini, F., Banfi, P., Lunetta, C., Rossi, G., Castelnuovo, G., Marconi, A., ... & Molinari, E. (2012). Respiratory function of people with amyotrophic lateral sclerosis and caregiver distress level: A correlational study. *BioPsychoSocial Medicine*, *6*(1), 1-6.

Pai, F. Y., & Huang, K. I. (2011). Applying the technology acceptance model to the introduction of healthcare information systems. *Technological Forecasting and Social Change*, *78*(4), 650-660.

Patient Image. (2014). Patient Image with Tongue Stick. Retrieved 11/16/2014 from http://www.broadenedhorizons.com/redman

Peek, S. T., Wouters, E. J., van Hoof, J., Luijkx, K. G., Boeije, H. R., & Vrijhoef, H. J. (2014). Factors influencing acceptance of technology for aging in place: A systematic review. *International Journal of Medical Informatics*, *83*(4), 235-248.

PC World. (2015). How much does it really cost to own a smartphone? Retrieved on December 22, 2015 from http://www.pcworld.com/article/168486/smartcost.html

Penalties. (2014). HIPAA/HITECH Penalties. Retrieved on 11/18/2014 from http://apps.missouristate.edu/human/training/hipaatraining/trainingtext.htm

Perrin, C., Unterborn, J. N., Ambrosio, C. D., & Hill, N. S. (2004). Pulmonary complications of chronic neuromuscular diseases and their management. *Muscle & Nerve*, *29*(1), 5-27.

PhonesThrones. (2014). UN Study on Cellphones . Retrieved on 11/4/14 from http://newsfeed.time.com/2013/03/25/more-people-have-cell-phones-than-toilets-u-n-study-shows/

Prentice-Dunn, S., & Rogers, R. W. (1986). Protection motivation theory and preventive health: Beyond the health belief model. *Health Education Research*, *1*(3), 153-161.

Prochaska, J. O., & DiClementi, C. C. (1984). The Transtheoretical approach: Crossing the traditional boundaries of therapy. Melbourne: Krieger Publishing Company.

PubMed. (2016). US National Library of Medicine & National Institutes of Health. Available at http://www.ncbi.nlm.nih.gov/pubmed/

Reiter, K., Pernath, N., Pagel, P., Hiedi, S., Hoffmann, F., Schoen, C., & Nicolai, T. (2011). Risk factors for morbidity and mortality in pediatric home mechanical ventilation. *Clinical Pediatrics*, *50*(3), 237-243.

Respiration. (2015). In *Encyclopaedia Britannica Online Academic Edition*. Encyclopædia Britannica Inc. Retrieved on December 6, 2015 from http://www.britannica.com/science/human-respiratory-system.

Retina Imaging. (2014). Peek Smartphone Tool. Retrieved 11/12/2014 from http://www.st-andrews.ac.uk/news/archive/2013/title,223732,en.php

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Glencoe, New York: Simon and Schuster.

Rogers, E.M. (1962). *Diffusion of innovations.* New York: The Free Press.

Ronis, D. L. (1992). Conditional health threats: Health beliefs, decisions, and behaviors among adults. *Health Psychology*, *11*(2), 127.

Rosenstock, I. M. (1974). Historical origins of the health belief model. *Health Education & Behavior*, *2*(4), 328-335.

Rotter, J. B. (1954). Social learning and clinical psychology. Englewood Cliffs, NJ, US: Prentice-Hall, Inc.

Rubin, A. (2011). TedTalk: All your devices can be hacked. Retrieved on 3/19/17 from https://www.ted.com/talks/avi_rubin_all_your_devices_can_be_hacked

Russell, P. M., Mallin, M., Youngquist, S. T., Cotton, J., Aboul-Hosn, N., & Dawson, M. (2014). First "Glass" Education: Telementored Cardiac Ultrasonography Using Google Glass-A Pilot Study. *Academic Emergency Medicine*, *21*(11), 1297-1299.

Schlachta, C. M., Kent, S. A., Lefebvre, K. L., McCune, M. L., & Jayaraman, S. (2009). A model for longitudinal mentoring and telementoring of laparoscopic colon surgery. *Surgical Endoscopy*, *23*(7), 1634-1638.

Schulam, P. G., Docimo, S. G., Saleh, W., Breitenbach, C., Moore, R. G., & Kavoussi, L. (1997). Telesurgical mentoring. *Surgical Endoscopy*, *11*(10), 1001-1005.

SCI Facts. (2015). Facts and figures at a glance. NSCISC National Spinal Cord Injury Statistical Center. Retrieved on March 14, 2016 from https://www.nscisc.uab.edu/reports.aspx

SCI Life. (2016). SCI life expectancy, University of Alabama website. Retrieved on March 19, 2016 from https://www.nscisc.uab.edu/Public/Facts%202015.pdf

Slutsky, A. S. (1993). Mechanical ventilation. American College of Chest Physicians' Consensus Conference. *CHEST Journal*, *104*(6), 1833-1859.

Slutsky, A. S. (2015). History of mechanical ventilation. From Vesalius to ventilator-induced lung injury. *American Journal of Respiratory and Critical Care Medicine, 191*(10), 1106-1115.

Smith, B., Kurili, A., & Hanley, J. (2014). Let me breathe! Remote ventilator patient management. University of Michigan IT Symposium. Retrievable from http://cio.umich.edu/michigan-it/michigan-it-symposium-presentations-2014.php

Smith, S. (2012). 4 Common Sense Tips for Creating Surveys that Work. Retrieved on June 1, 2016 from https://www.qualtrics.com/blog/creating-surveys/

Snyderman, C. H., Gardner, P. A., Lanisnik, B., & Ravnik, J. (2016). Surgical telementoring: A new model for surgical training. *The Laryngoscope, 126*(6), 1334-1338.

Some Images. (2014). Dog, tongue, home, nailbed images. Retrieved 11/18/2014 from https://www.google.com/imghp?gws_rd=ssl

Spinal Stats. (2015). Spinal cord injury (SCI) facts and figures at a glance. Retrieved on December 14, 2015 from https://www.nscisc.uab.edu/PublicDocuments/fact_figures_docs/Facts%202015.pdf

SRM. (2016). Social Research Methods – Research Methods Knowledge Base. Retrieved on May 4, 2016 from http://www.socialresearchmethods.net/kb/survtype.php

Sun, Y., Wang, N., Guo, X., & Peng, Z. (2013). Understanding the acceptance of mobile health services: A comparison and integration of alternative models. *Journal of Electronic Commerce Research*, *14*(2), 183.

Svendsen, G. B., Johnsen, J. A. K., Almås-Sørensen, L., & Vittersø, J. (2013). Personality and technology acceptance: the influence of personality factors on the core constructs of the Technology Acceptance Model. *Behaviour & Information Technology, 32*(4), 323-334.

Tessier. (2016). @mHI: The 12 Clusters of mHealth. Retrieved on May 3, 2016 from http://mobihealthnews.com/1091/mhi-the-12-clusters-of-mhealth

Tetraplegia. (2014). Number with Tetraplegia in the U.S. Retrieved on 11/9/2014 from http://www.sci-info-pages.com/facts.html

Trilogy. (2014). Trilogy 100 waveforms and settings screens. Retrieved on 11/18/2014 from http://www.ahcah.com/Manuals/Trilogy%20100%20Patient%20Manual.pdf

Trochim, W. (2001). Research Methods Knowledge Base. Available at http://www.anatomyfacts.com/research/researchmethodsknowledgebase.pdf

Ultrasound. (2014). Smartphone ultrasound. Retrieved 11/18/2014 from http://venturebeat.com/2011/10/11/new-smartphone-ultrasound-device-is-finally-available/

Venkatesh, V., & Bala, H. (2008). Technology acceptance model 3 and a research agenda on interventions. *Decision Sciences*, *39*(2), 273-315.

Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management Science*, *46*(2), 186-204.

Venkatesh, V., Thong, J. Y., & Xu, X. (2012). Consumer acceptance and use of information technology: Extending the unified theory of acceptance and use of technology. *MIS Quarterly*, *36*(1), 157-178.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS Quarterly, 27*(3), 425-478.

Ventilators. (2016). Images from Google search of "pictures of mechanical ventilators". Retrieved on March 27, 2016 from https://www.google.com/?gws_rd=ssl#q=pictures+of+mechanical+ventilators

VentQuest. (2017). Qualtrics Assisted Ventilation Clinic Questionnaire. Accessible at http://bit.ly/2hq1BQf

Vitacca, M., Assoni, G., Pizzocaro, P., Guerra, A., Marchina, L., Scalvini, S., ... & Balbi, B. (2006). A pilot study of nurse-led, home monitoring for patients with chronic respiratory failure and with mechanical ventilation assistance. *Journal of Telemedicine and Telecare, 12*(7), 337-342.

Vitacca, M., Bianchi, L., Guerra, A., Fracchia, C., Spanevello, A., Balbi, B., & Scalvini, S. (2009). Tele-assistance in chronic respiratory failure patients: A randomized clinical trial. *European Respiratory Journal*, *33*(2), 411-418.

Vitacca, M., Comini, L., Assoni, G., Fiorenza, D., Gilè, S., Bernocchi, P., & Scalvini, S. (2012). Tele-assistance in patients with amyotrophic lateral sclerosis: Long term activity and costs. *Disability and Rehabilitation: Assistive Technology, 7*(6), 494-500.

Vitacca, M., Escarrabill, J., Galavotti, G., Vianello, A., Prats, E., Scala, R., ... & Balbi, B. (2007a). Home mechanical ventilation patients: A retrospective survey to identify level of burden in real life. *Monaldi Archives for Chest Disease*, *67*(3), 142.

Vitacca, M., Guerra, A., Assoni, G., Pizzocaro, P., Marchina, L., Scalvini, S., & Balbi, B. (2007b). Weaning from mechanical ventilation followed at home with the aid of a telemedicine program. *Telemedicine and e-Health, 13*(4), 445-450.

Vitacca, M., Paneroni, M., Trainini, D., Bianchi, L., Assoni, G., Saleri, M., ... & Gonçalves, M. R. (2010). At home and on demand mechanical cough assistance program for patients with amyotrophic lateral sclerosis. *American Journal of Physical Medicine & Rehabilitation*, *89*(5), 401-406.

Wade, V., Gray, L., & Carati, C. (2016). Theoretical frameworks in telemedicine research. *Journal of Telemedicine and Telecare*, *23*(1), 181-187.

Waegemann (2009). @mHI: The 12 clusters of mHealth. Retrieved May 3, 2016 from http://mobihealthnews.com/1091/mhi-the-12-clusters-of-mhealth

West, J. B. (2012). *Respiratory physiology: The essentials.* Phidelphia, PA:Lippincott Williams & Wilkins.

WHO. (2016). Spinal cord injury fact sheet. World Health Organization. Retrieved on March 15, 2016 from http://www.who.int/mediacentre/factsheets/fs384/en/

Wilcox, M. E., & Adhikari, N. K. (2012). The effect of telemedicine in critically ill patients: Systematic review and meta-analysis. *Critical Care*, *16*(4), 1-12.

Winn, S., McKeown, P., Lotfipour, S., Maguire, G. A., Youm, J. H., Wiechmann, W., & Fox, J. C. (2015). Remote, synchronous, hands-on ultrasound education. *Telemedicine and e-Health*, *21*(7), 593-597.

Xu, R., Frey, R. M., Fleisch, E., & Ilic, A. (2016). Understanding the impact of personality traits on mobile app adoption–Insights from a large-scale field study. *Computers in Human Behavior*, *62*, 244-256.

Yang, C. W., Wang, H. C., Chiang, W. C., Chang, W. T., Yen, Z. S., Chen, S. Y., ... & Lin, F. Y. (2008). Impact of adding video communication to dispatch instructions on the quality of rescue breathing in simulated cardiac arrests—a randomized controlled study. *Resuscitation*, *78*(3), 327-332.

Yuan, S., Ma, W., Kanthawala, S., & Peng, W. (2015). Keep using my health apps: Discover users' perception of health and fitness apps with the UTAUT2 model. *Telemedicine and e-Health*, *21*(9), 735-741.

Zamarrón, C., Morete, E., & González, F. (2014). Special paper–new methods telemedicine system for the care of patients with neuromuscular disease and chronic respiratory failure. *Archives of Medical Science*, *10*(5), 1047.

Appendix

Appendix A: The Alternative Hypotheses

Hypoth-eses	**Definitions of the Alternative Hypotheses**
$H1_A$	There is a significant relationship between *Perceived Usefulness* and *Intent to Use*
$H2_A$	There is a significant relationship between *Perceived Ease of Use* and *Intent to Use*
$H3_A$	There is a significant relationship between *Perceived Ease of Use* and *Perceived Usefulness*
$H4_A$	There is a significant relationship between *Own/Access* and *Perceived Usefulness*
$H5_A$	There is a significant relationship between *Own/Access* and *Perceived Ease of Use*
$H6_A$	There is a significant relationship between *Own/Access mobile devices* and *Intent to Use*
$H7.1_A$	There is a significant relationship between Respondents (Pts/CGFF/CGP) and *Intent to Use*
$H7.2_A$	There is a significant relationship between Age and *Intent to Use*
$H7.3_A$	There is a significant relationship between Sex and *Intent to Use*
$H7.4_A$	There is a significant relationship between *Diagnoses* and *Intent to Use*
$H7.5_A$	There is a significant relationship between *Respiration Assist Device* and *Intent to Use*
$H7.6_A$	There is a significant relationship between *Vent Hrs/Day* and *Intent to Use*
$H7.7_A$	There is a significant relationship between *Tracheostomy* and *Intent to Use*
$H7.8_A$	There is a significant relationship between *Own/Access to mobile devices* and *Intent to Use*
$H7.9_A$	There is a significant relationship between *Videoconference Before* and *Intent to Use*
$H7.10_A$	There is a significant relationship between *Downloading Applications Before* and *Intent to Use*
$H7.11a_A$	There is a significant relationship between *Own/Access to Mobile Devices* and *Intent to Use*
$H7.11b_A$	There is a significant relationship between *Number of Devices Owned/Access* and *Intent to Use*
$H7.12_A$	There is a significant relationship between *Cellular/WiFi/Internet Connectivity* and *Intent to Use*
$H7.13_A$	There is a significant relationship between *Miles to the nearest Emergency Department* and *Intent to Use*
$H7.14_A$	There is a significant relationship between *Miles to the Assisted Ventilation Clinic* and *Intent to Use*

Appendix B: Core Constructs of 18 Studies Combining Technology Acceptance and Health Behavior Research Models

1. (Kim & Park, 2012) – "Development of a Health Information Technology Acceptance Model Using Consumer's Health Behavior Intention"

Health Information Technology Acceptance Model (HITAM) = TAM3+HBM+TPB =

[TAM3 Behavior < (Behavioral Intention < (Subjective Norm; *Perceived Usefulness* (Image, Job Relatedness, Output Quality, Result Demonstrability); *Perceived Ease of Use* (Computer Self-Efficacy, Perception of External Control, Computer Anxiety, Computer Playfulness, Perceived Enjoyment, Objective Usability)]

[HBM Behavior < (Behavioral Intention < (Perceived Benefit, Perceived Barrier, Perceived Threat, Cues to Action) < (Demographic Variables (Gender, Age (<19, 20-29, 30-39, 40-49, 50-59, > 60) Occupation, Education, Chronic Diseases, Monthly Income), Perceived Susceptibility, Perceived Seriousness)]

[TPB Behavior < (Behavioral Intention < (Attitude, Subjective Norm, Perceived Behavioral Control) < Behavioral Beliefs, Normative Beliefs, Efficacy Beliefs)]

2. (Melas, Zampetakis, et al., 2011) (Survey Questions Included) – "Modeling the acceptance of clinical information systems among hospital medical staff: An extended TAM model"

Extended TAM Model (ETAM) = [Behavioral Intention to Use (BI = predict I will use IT regularly in future; IT will be my favorite tech for my work; I intend to use IT in my work) < (Attitudes toward use (ATT= Using IT in clin practice advisable; pleasant idea; enjoy using IT; will be satisfied using IT); (*Perceived Usefulness* (PU = IT enable me to be quicker in tasks; improve my job performance; increase productivity; job effectiveness; easier to do my job; IT useful in my job) (ICT feature demands); *Perceived Ease of Use* (PEoU = learn to use is easy; easy to get IT to do what I want it to do; IT interactions clear and understandable; IT flexible to interact; easy to become skillful with IT) (ICT knowledge)) < Physician specialty]

3. (Moores, 2012) the research model – (Survey Questions Included) – "Towards an integrated model of IT acceptance in healthcare"

Integrated Model of IT Acceptance in HC (IMITAHC) = [Depth and Breadth of Use = (PEU(Information Quality = accuracy, content format, timeliness) + PEoU(Enabling Factors = computing support, self-efficacy)) + experience]

4. (Sun et al., 2013) – Survey questions included – "Understanding the acceptance of mobile health services: A comparison and integration of alternative models"

SUNM (Sun et al. model) = [Intention to Adopt (AI), Attitude (ATTD), Subjective Norm (SN), Perceived Behavioral Control (PBC), *Perceived Usefulness* (PU), *Perceived Ease of Use* (PEoU), Perceived Vulnerability (PV), Perceived Severity (PS), Response Efficacy (RE), Self-Efficacy (SE), Response Cost (RC)]

5. (Klein, Mogles, & van Wissen, 2013) no questions included – in process – "An Intelligent Coaching System for Therapy Adherance"

Computerized Behavior Intervention Model (CombiM) = [Susceptibility (HBM), Severity (HBM), Pros/Cons (TPB/AF/HBM), Emotions (SCT/AF), Social Norms (TPB/AF), Barriers (HBM), Skills (TPB/SCT), Cues (HBM), Threats (HBM), Attitude (TPB/AF), Self-Efficacy (RPM/SCT/TPB), Coping Strategies (SRT/RPM), Mood (TPB), High-Risk Situations (RPM), Awareness (TTM), Motivation (HBM/TTM), Commitment (TTM)]

.... AF = attitude formation; SRT = Self Regulating Theories; RPM = Relapse Prevention Model,

6. (Faqih & Jaradat, 2015) – Questions included – "Assessing the moderating effect of gender differences and individualism-collectivism at individual-level on the adoption of mobile commerce technology: TAM3 perspective"

Mobile Commerce TAM3 (MCTAM3) = [*Perceived Usefulness* (PU), *Perceived Ease of Use* (PEOU), Self-Efficacy (SE), Perceptions of External Control (PEC), Playfulness (PLAY), Anxiety (ANX), Subjective Norm (SN), Voluntariness (VOL), Image (IMG), Output Quality (OUT), Result Demonstrability (RES), Behavior Intention (BI), Actual Use (AU), Individualism-Collectivism at Individual Level (ICIL) + demographics (gender, age, monthly expense)]

7. (Holden & Karsh, 2010) – Questions included "The Technology Acceptance Model: Its past and its future in health care"

TAM+TAM2+UTAUT+TPB (TAM/2UTAUTPB) = [*Perceived Usefulness*, *Perceived Ease of Use*, Attitude, Behavioral Intention to Use, Actual Use, Subjective Norm, Image, Job Relevance, Output Quality, Results Demonstrability, Performance Expectancy, Effort Expectancy, Social Influence, Facilitating Conditions, Behavioral Beliefs, Normative Beliefs, Control Beliefs, Perceived Behavioral Control]

8. (Yuan et al., 2015) – Questions Included. "Keep Using my Health Apps: Discover Users' Perception of Health and Fitness Apps with the UTAUT2 Model"

Unified Theory of Acceptance and Use of Technology Model (UTAUT2) = [Performance Expectancy, Effort Expectancy, Social Influence, Hedonic Motivations, Habit, Price Value, Facilitating Conditions, Behavioral Intention]

9. (Lee, Kozar, & Larsen, 2003) Meta-analysis "The Technology Acceptance Model: Past, Present, and Future"

Summary of TAM Variables (STAMV) = [Voluntariness, Relative Advantage, Compatibility, Complexity, Observability, Trialability, Image, Self-Efficacy, End User Support, Objective Usability, Personal Innovativeness, Computer Playfulness, Social Presence, Subjective Norms/Social Influence, Visibility, Job Relevance, Computer Attitude]

10. (Pai & Huang, 2011) Questions included. – "Applying the Technology Acceptance Model to the introduction of healthcare information systems"

TAM + Health Information Technology (TAMHIT) = [Information Quality, Service Quality, System Quality, *Perceived Usefulness*, *Perceived Ease of Use*, Intention to Use]

11. (Gao, Li, & Luo, 2015) – no questions included "An Empirical Study of wearable technology acceptance in healthare"

Wearable Technology Acceptance in Health Care (WTAHC) = [Performance Expectancy, Hedonic Motivation, Effort Expectancy, Functional Congruence, Self-Efficacy, Social Influence, Perceived Vulnerability, Perceived Severity, Perceived Pricy Risk, Behavioral Intention]

12. (Ahadzadeh et al., 2015) – Questions included. "Integrating Health Belief Model and Technology Acceptance Model: An Investigation of Health-Related Internet Use"

Integrated HBM and TAM Health-Related Internet Use Model (IHBMTAMHRIU) = [Health-Related Internet Use, Internet Use for Communication, Internet Use for Health Information Seeking, Perceived Ease of Internet Use, Attitude Towards Internet Use, *Perceived Usefulness* of Internet, Perceived Health Risk, Perceived Severity of Chronic Diseases, Perceived Susceptibility to Chronic Diseases, Health Consciousness]

13. (Peek et al., 2014) – Meta-analysis. "Factors influencing acceptance of technology for aging in place: A systematic review"

AgeInPlaceSysRev = [Concerns regarding technology (high cost, privacy implications, forgetting or losing technology, false alarms, obtrusiveness, burdening children, ineffectiveness, impracticality, low ease of use, negative effect on health, no control over technology, stigmatization); Benefits expected of technology (increased safety, *Perceived Usefulness*, increased independence, reduced burdenon family caregivers); Need for technology (perceived need, subjective health status); Alternatives to technology (help by family or spouse, current technology); Social influence (influence of family and friends, influence of professional caregivers, use of peers); Characteristics of older adults (desire to age in place, cultural background, familiarity with electronic technology, housing type)]

14. (Magsamen-Conrad et al., 2015) – "Bridging the divide: Using UTAUT to predict multigenerational tablet adoption practices"

TabletUTAUT = [Performance expectancy, Effort expectancy, Social influence, Facilitating conditions, Behavioral intention (Generations = Builders (1900-1946), Boomers (1946-1964), GenX (1965-1982), GenY(1982-1991)); Demographics (age, gender, experience of tablet use, hours of tablet use) effort expectancy]

15. (Li, Wu, Gao & Shi, 2016) – "Examining individuals' adoption of healthcare wearable devices: An empirical study from privacy calculus perspective"

PrivacyCalcMod = [Health information sensitivity, Personal innovativeness in IT, Legislative protection, Perceived prestige, Perceived informativeness, Functional congruence, Perceived privacy risk, Perceived benefit, Adoption intention, Actual adoption behavior; Demographics: Gender (F/M), Age (<=25/ 26-35/ 36-45/ >=46), Education

(BS/MS/Doctorate), Internet Experience (<1yr, 1-2yrs/ 3-5yrs/ >5yrs), Health Status (Healthy/ Poor Health/ Unhealthy)]

16. (Nisha, Iqbal, Rifat & Idrish, 2015) = “Mobile Health Services: A New Paradigm for Health Care Systems”

MobileMod = [Performance Expectancy, Effort Expectancy, Social Influence, Facilitating Conditions, Information Quality, Trust, Behavioral Intention, Usage Behavior]

17. (Cimperman, Brencic & Trkman, 2016) – Has Questions - “Analyzing older users’ home telehealth services acceptance behavior – applying an Extended UTAUT model”

ExtUTAUTMod = [Performance Expectancy (PE), Effort Expectancy (EE), Social Influence (SI), Facilitating Conditions (FC), Perceived Security (PS), Computer Anxiety (CA), Doctor’s Opinion Influence (DOC), Behavioral Intention to Use (BI)]

18. (McClenahan et al., 2006) – Questions included. “Testicular self-examination: a test of the health belief model and the theory of planned behavior”

TesticTestMod = [Behavior, Intention, Attitude, Subjective Norms, Perceived Behavioral Control, Self-Efficacy, Susceptibility, Severity, Benefits, Barriers, Health Motivation, Cues to Action, Past Behavior]

Appendix C: Constructs from 18 Selected Papers Relevant to This Study

Construct	Construct Definition	References
Accessibility	Physical accessibility: the extent to which someone has physical access to the hardware needed to use the system Information accessibility: the ability to retrieve the desired information from the system	Lee et al., 2003
Affect Toward Use	Feelings of joy, elation, or pleasure; or depression, disgust, displeasure, or hate associated by an individual with a particular act.	Thompson et al., 1991
Anxiety	An individual's apprehension, or even fear, when she/he is faced with the possibility of using the technology	Lee et al., 2003
Attitude	The degree to which a person likes or dislikes the object; A mental state involving beliefs, emotions, and dispositions; An individual's positive or negative feelings about performing the target behavior	Davis et al., 1989; Fishbein and Ajzen, 1977;
Awareness	Conscious knowledge of your condition and the threat and influence of current behavior	Klein et al., 2013
Actual Use/Behavior Actual	The degree to which a person actually uses a particular technology	Jen et al., 2009
Behavioral or Adoption Intention	A measurment of the strength of one's intention to perform a specified behavior	Jen et al., 2009
Commitment	An intellectual or emotional binding to a course of action	Klein et al., 2013
Compatibility	The degree to which an innovation is perceived as being consistent with the existing values, needs, and past experiences of potential adopters	Moore and Benbasat, 1991; Lee et al., 2013
Complexity	The degree to which an innovation is perceived as being difficult to understand or use	Lee et al., 2003; Thompson et al., 1991
Computer Playfulness	The degree of cognitive spontaneity in microcomputer interactions	Lee et al., 2003
Coping Strategies	The ability to deal with tempting situations and cues	Klein et al., 2013
Cues to Action	Environmental or physical stimuli	Klein et al., 2013
Effort Expectancy	The degree of ease associated with use of the technology.	Venkatesh et al., 2003
Emotions	Feelings and cognitive appraisal related to the behavior change	Klein et al., 2013

Appendix C Table (continued)

Construct	Construct Definition	References
End User Support	High levels of support that promotes more favorable beliefs about the system among users as well as MIS staffs	Lee et al., 2003
Experience	Experience gained	Lee et al., 2003
Extrinsic Motivation	The perception that users will want ot perform an activity because it is perceived to be instrumental in achieving valued outcomes that are distinct from the activity itself, such as improved job performance, pay, or promotions	Davis et al., 1992
Facilitating Conditions	The control beliefs relating to resource factors such as time and money and IT compatibility issues that may constrain usage; Objective factors in the environment that observers agre make an act easy to do	Lee et al., 2003; Thompson et al., 1991
Functional Congruence	Adapted from self-congruency theory, to represent the perceived suitability of a product to fulfill the functional and basic product-related needs .	Huber et al., 2010
Habit	Self-reported perception of automatically engaging in a certain behavior	Venkatesh, Thong, Xu, 2012
Health Status	Having any diseases or comorbidities	Kim & Park, 2012
Hedonic Motivation (Perceived Benefit)	The fun or pleasure derived from using a technology.	Venkatesh, Thong, Xu, 2012
High-Risk Situations	Contexts and environments that influence a person's behavior	Klein et al., 2013
Image	The degree to which use of an innovation is perceived to enhance one's image or status in one's social system	Lee et al., 2003
Intrinsic Motivation	The perception that users will want ot perform an activity because it is perceived to be instrumental in achieving valued outcomes that are distinct from the activity itself, such as improved job performance, pay, or promotions; The perception that users will want to perform an activity for no apparent reinforcement other than the process of performaing the activity per se.	Davis et al., 1992
Job Relatedness; Job Relevance; Job fit	The capabilities of a system to enhance and individual's job performance	Lee et al., 2003; Thompson et al., 1991

Appendix C Table (continued)

Construct	Construct Definition	References
Mood	A temporary state of mind defined by feelings and dispositions	Klein et al., 2013
Motivation	Incentive to perform goal-directed actions	Klein et al., 2013
Objective Usability	A construct that allows for a comparison of systems on the actual level of effect regarding to complete specific tasks	Lee et al., 2003
Observability	The degree to which the results of an innovation are observable to others	Lee et al., 2003
Outcome Expectations	Outcome expectations relate to the consequences of the behavior based on empirical evidence - job related and individual goals	Compeau and Higgins, 1995b
Perceived (Health) Threat	Perceived risk of continuing to perform the behavior	Klein et al., 2013
Perceived Barrier	Practical obstacles that prevent behavior change	Klein et al., 2013
Perceived Behavioral Control	Reflects perceptions of internal and external constraints on behavior and encompasses self-efficacy, and resource and technology facilitating conditions	Ajzen 1991; Taylor and Todd 1995a, 1995b
Perceived Benefit	One's belief in the efficacy of the advised action to solve (a threat or problem.)	Sun et al., 2013
Perceived Ease of Use	The degree to which a person believes that using a system would be free of effort	Davis, 1989
Perceived Enjoyment	The extent to which the activity of using a specific system is perceived to be enjoyable in its own right, aside from any performance consequences resulting from system usage	Lee et al., 2003
Perceived Enjoyment	The extent to which the activity of using a specific system is perceived to be enjoyable in its own right, aside from any performance consequences resulting from system usage	Lee et al., 2003
Perceived Severity (Perceived Health Threat)	The severity of the behavior's consequences	Klein et al., 2013
Perceived Susceptibility	The likelihood of being affected by the behavior's consequences	Klein et al., 2013
Perceived Usefulness	The degree to which a person believes that using a particular technology would enhance their job performance	Davis, 1989

Appendix C Table (continued)

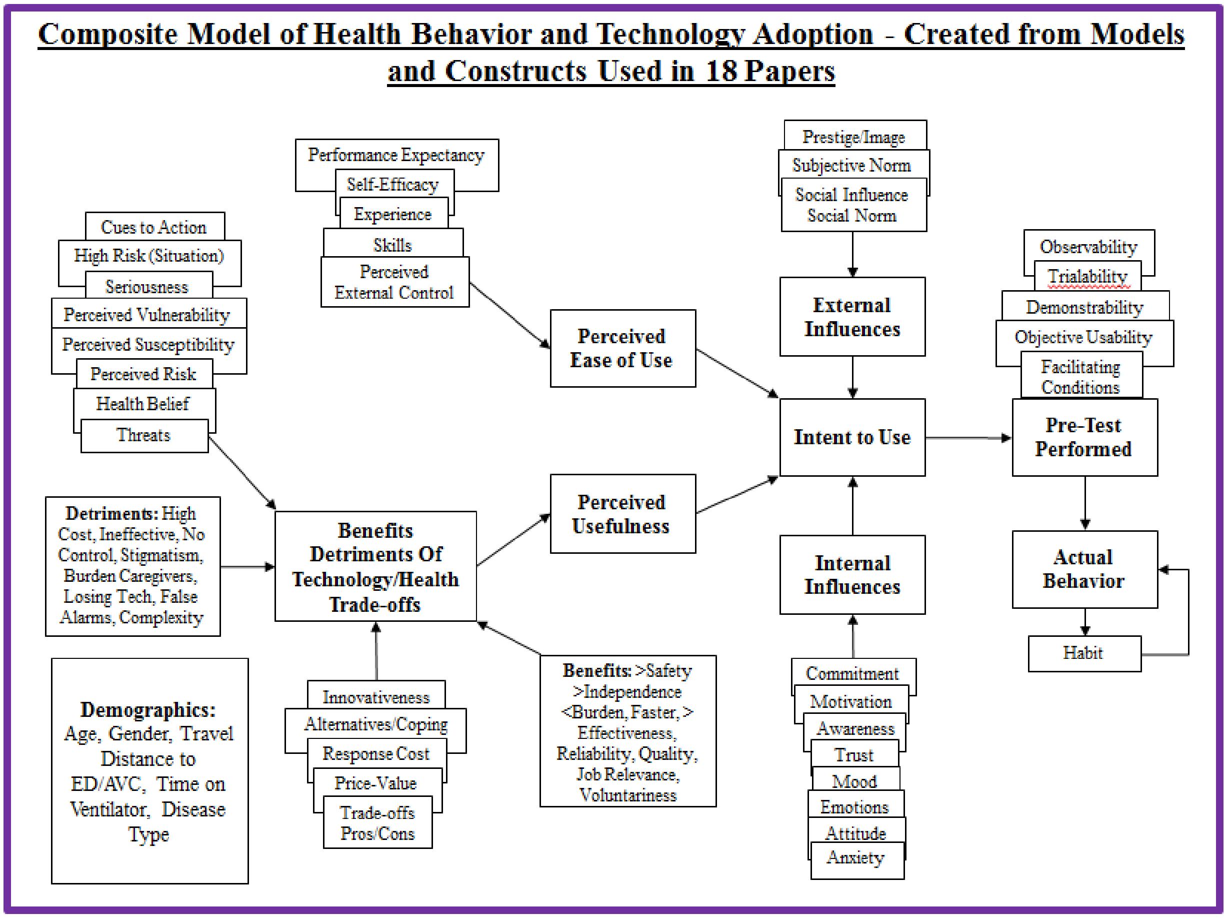
Construct	Construct Definition	References
Perceived Vulnerability (Perceived Health Threat)	The probability that one will experience harm, while perceived severity refers to the degree of harm from unhealthy behavior	Sun et al., 2013
Perception of External Control	The extent to which individuals have adequate external resources to perform a behavior	Sun et al., 2013
Performance Expectancy (Perceived Benefit)	Performance expectancy is defined as the degree to which adopting a technology will bring effectiveness to users in performing certain activities	Venkatesh et al., 2003, 2012
Personal Innovativeness	An individual trait reflecting a willingness to try out any new technology	Lee et al., 2013
Price Value	Consumers' cognitive trade-off between the perceived benefits of the technology (e.g. applications) and the monetary cost for using them	Yuan et al., 2015
Pros/Cons	Beliefs about the importance of behavior change	Klein et al., 2013
Relative Advantage	The degree to which an innovation is perceived as being better than its precursor	Moore and Benbasat, 1991; Lee et al., 2013
Reliability; System (Output or Info Quality)	Whether the system is error-free, consistently available and secure; The perception how well the system performs tasks that match with job goals; reliability includes quality of output and demonstrability of result, which suggests that it can come from either a direct experience with the technology or an indirect experience, gained through information gathered through other consumers	Kim, H. W., Chan, et al., 2007
Response Cost	Response cost is an external control because it is relevant to the resources (especially the money and effort) spent for learning and using the technology	Sun et al., 2013
Response Efficacy	The more effective a technology is in reducing a threat or solving problems, the more likely patient will be to adopt the technology	Sun et al., 2013
Result Demonstrability	The degree to which the results of adopting/using the IS innovation are observable and communicatable to others	Lee et al., 2003
Result Demonstrability	The degree to which the results of adopting/using the technology innovation are observable and communicatable to others	Lee et al., 2003
Self-Efficacy	The belief that one has the capability to perform a particular behavior; Perceived behavioral control	Lee et al., 2003; Klein et al., 2013;

Appendix C Table (continued)

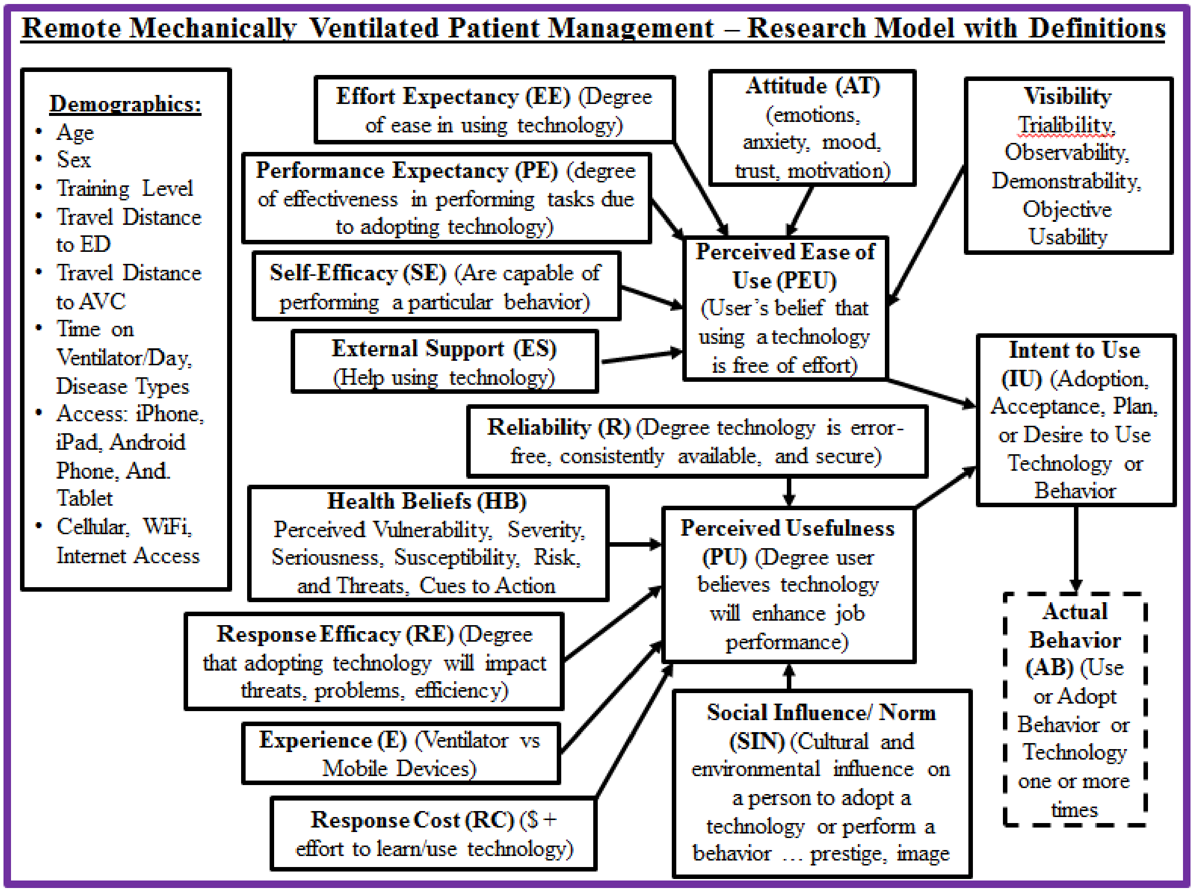
Construct	Construct Definition	References
Skills	Experiences and capabilities to overcome barriers	Klein et al., 2013
Social Influence/ Social Norm	Person's perception that most people who are important to him think he should or should not perform the behavior in question/ The influence of a person's culture and environment	Lee et al., 2003; Klein et al., 2013;
Social Presence	The degree to which a medium permits users to experience others as being psychologically present	Lee et al., 2003
Subjective Norm	Person's perception that most people who are important to him think he should or should not perform the behavior in question	Ajzen 1991; Davis et al., 1989; Fishbein and Azjen, 1977; Lee et al., 2003
Subjective Norm	Social pressure or community competition, resulting in consumers forming positive attitude.	Kim & Park, 2012
Trialability	The degree to which an innovation may be experimented with before adoption	Lee et al., 2013
Visibility	The degree to which the innovation is visible in the organization	Lee et al., 2013
Voluntariness	The degree to which use of the innovation is perceived as being voluntary, or of free will	Lee et al., 2013

Appendix D: Composite Technology Adoption and Health Behavior Model

Based on the Focus 18 Research Papers



Appendix E: Composite Technology Adoption and Health Behavior Model Based on Four Key Research Papers

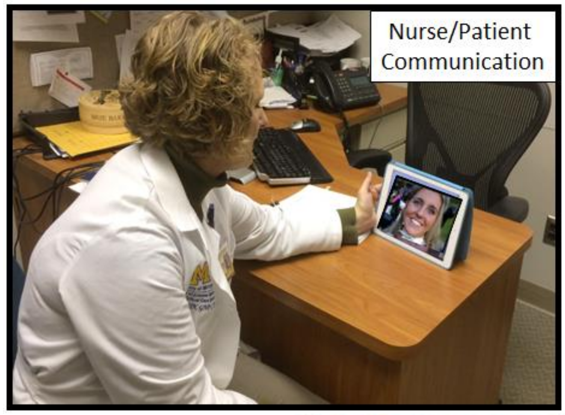


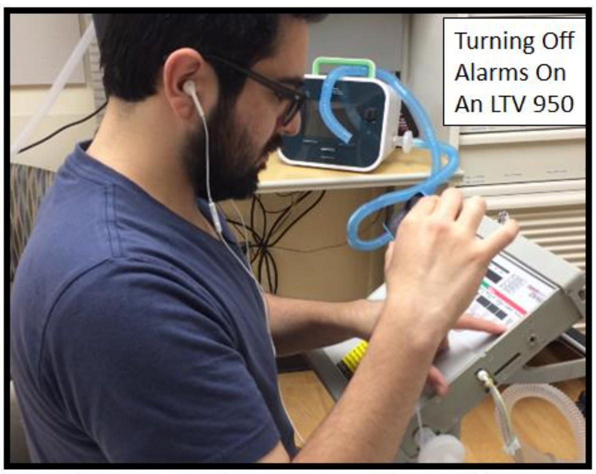
Appendix F: Original Expanded Questionnaire

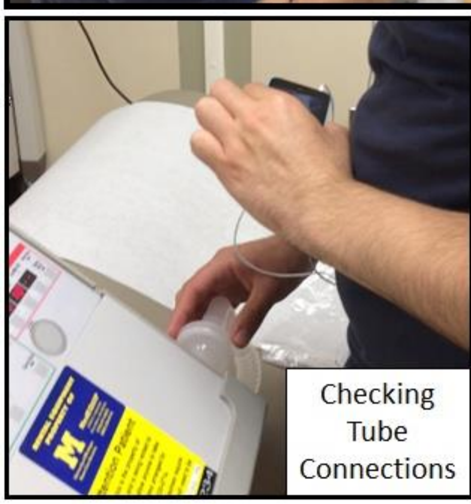
Assisted Ventilation Clinic (AVC) Questionnaire:

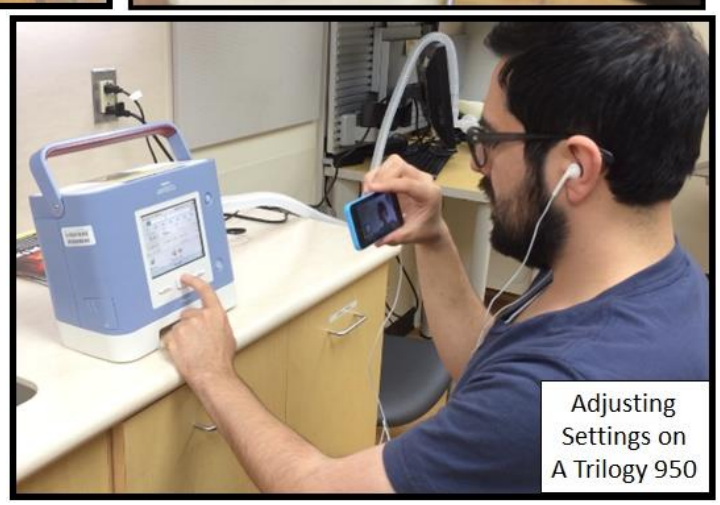
Telemedicine includes using videoconferencing for communications between the nurse or respiratory therapist in the AVC and the patient or caregiver(s) at home. We would like to find out what you think about using videoconferencing for remote ventilated patient management. Here are some examples of how videoconferencing can be used.

Using a smartphone and videoconferencing, a nurse or respiratory therapist can communicate with the patient and caregiver, provide guidance in resolving alarms, adjusting ventilator and cough assist device settings, trouble-shoot tube and ventilator problems, and assist in patient care.









Demographics: Please select the best answers below … (15 questions)

- I am a: ☐ Patient ☐ Caregiver
- Age:

☐18-29 ☐30-39 ☐40-49 ☐ 50-59 ☐60-69 ☐70-79 ☐ 80 or more years

- Gender: ☐Male ☐Female ☐Other
- Type of Disease:

☐ALS ☐SCI ☐DMD ☐CP ☐MS ☐Muscular dystrophy ☐OSA ☐Other

- What type of respiratory assist device do you use?

☐None ☐CPAP ☐BiPAP ☐LTV ☐Trilogy ☐Cough Assist Device ☐Other

- How many hours a day do you use your respiratory (ventilator) device?

☐ 0 to 4 hours ☐5 to 12 hours ☐13 to 24 hours

- Do you have a tracheostomy tube? ☐ YES ☐ NO
- ??????Experience Level as a Caregiver: ??????

☐ New Caregiver ☐ Average ☐ Good ☐ Very Good ☐ Expert

- Have you ever used videoconferencing (e.g. Skype, FaceTime)? ☐ Yes ☐ No
- Have you ever downloaded applications on your smartphone? ☐ Yes ☐ No
- Do you own or have access to a smartphone between 8am-5pm, Monday through Friday?

  ☐ Yes ☐ No
- What type of smartphone?

☐ Apple iPhone ☐ Android smartphone ☐ I don't own or have access to a smartphone

- Approximately how many miles are you from the nearest emergency department (ED)?

☐ Less than 25 miles ☐26 to 50 ☐51 to 75 ☐ 75 to 100 ☐ More than 100 miles

- Approximately how many miles are you from the UMHS Assisted Vent Clinic?

☐ Less than 25 miles ☐26 to 50 ☐51 to 75 ☐ 75 to 100 ☐ More than 100 miles

- Do you have either cellular or WiFi internet access in your home? ☐ Yes ☐ No

===

(1) *Perceived Ease of Use*

- PEU1: Learning to operate a smartphone will be easy for me. [adapted from Sun et al., 2013 - .870/39.803]
- PEU2: Learning to use videoconferencing will be easy for me. [adapted from Sun et al., 2013 - .870/39.803]
- PEU3: I can easily become skillful at using a smartphone for videoconferencing. [adapted from Sun et al., 2013 - .838/27.201]
- PEU4: Videoconferencing with a smartphone will be clear and understandable. [adapted from Venkatesh et al., 2003]

- PEU5: Overall, smartphones are easy to use.[adapted from Sun et al., 2013 - .872/46.693]

(2) Attitude (AT)

- AT1: Using smartphone videoconferencing for remote ventilated patient management is a good idea. [adapted from Sun et al., 2013 - .788/20.663]
- AT2: Using smartphone videoconferencing for remote ventilated patient management is wise. [adapted from Sun et al., 2013 - .833/33.502]
- AT3: I like the idea of using smartphone videoconferencing for remote ventilated patient management. [adapted from Ahadzadeh et al., 2015 - 0.895]

(3) Effort Expectancy (EE)

Using videoconferencing for remote ventilated patient management will:

- EE1: Be clear and understandable. [adapted from Yuan et al., 2015 - 0.98]
- EE2: Make interacting with clinicians easier. [adapted from Yuan et al., 2015 - 0.93]
- EE3: Be better than telephone (audio) only.
- EE4: Make adjusting ventilators and cough assist devices easier.
- EE5: Overall make caregiving easier.

(4) Performance Expectancy (PE)

Using videoconferencing for remote ventilated patient management will:

- PE1: Be highly useful for me as a caregiver. [adapted from Yuan et al., 2015 – 0.75]
- PE2: Help me solve caregiver problems more quickly. [adapted from Yuan et al., 2015 – 0.75]
- PE3: Help me to be more effective as a caregiver. [adapted from Nisha et al., 2015]
- PE4: Be convenient. [adapted from Nisha et al., 2015]
- PE5: Improve the quality of care. [adapted from Cimperman et al., 2016 – 0.88]
- PE6: Enhance the level of convenience in accessing medical care services. [adapted from Cimperman et al., 2016 – 0.85]

(5) Self-Efficacy (SE)

- SE1: It is easy for me to use smartphone videoconferencing. [adapted from Sun et al., 2013 -.874/39.765]
- SE2: I have the capability to use smartphone videoconferencing remote ventilated patient management. [adapted from Sun et al., 2013 - .82326.997]
- SE3: I am able to use smartphone videoconferencing without much effort. [adapted from Sun et al., 2013 - .867/35.582]
- SE4: I feel comfortable using smartphone videoconferencing. [adapted from Moores et al., 2012]
- SE5: I am able to use smartphone videoconferencing even if no one is around to show me how to use it. [adapted from Moores et al., 2012]
- SE6: Overall I am confident in my ability to use smartphone videoconferencing. [adapted from Moores et al., 2012]
- SE8: I could use smartphone videoconferencing if someone was available to help me. [adapted from Venkatesh et al., 2003]

(6) External Support (ES)

- ES1: I will need support in using videoconferencing with my smartphone.
- ES2: A support will be valuable in helping me use a smartphone for videoconferencing.
- ES3: I would like training in using videoconferencing in remote patient care.
- ES4: A user guide will help me to use videoconferencing.
- ES5: Remote support will help me resolve videoconferencing difficulties.
- ES6: Overall, I will need external support for using my smartphone for videoconferencing.
  [Moores et al., 2012; Venkatesh et al., 2003]

(7) *Perceived Usefulness* (PU)

I believe smartphone videoconferencing for remote patient management will:

- PU1: Improve the patient's quality of life. [adapted from Sun et al., 2013 - .802/32.662]
- PU2: Make patient care more convenient. [adapted from Sun et al., 2013 - .873/45.544]
- PU3: Make caregiving more effective in the patient's life. [adapted from Sun et al., 2013 - .867/33.364]
- PU4: Make caregiving easier. [adapted from Moores et al., 2012]
- PU5: Resolve patient care and management questions more quickly.
- PU6: Make caregiving more effective. [adapted from Sun et al., 2013 - .867/33.864]
- PU7: Make caregiving more efficient. [adapted from Holden et al., 2010]

(8) Reliability (R)

- R1: Smartphones are reliable (e.g. error-free connectivity, consistently available, and secure)? (1 strongly agree – 5 strongly disagree) [Kim, H. W., Chan, et al., 2007]

(9) Health Beliefs (HB)

Mechanically-ventilated **patients:**

- HB1: Are vulnerable to medical emergencies (e.g. ventilator problems).
- HB2: Are susceptible to medical emergencies (e.g. infections, mucus buildup).
- HB3: At risk of serious issues that require immediate attention.
- HB4: Develop conditions that can wait to be resolved during clinical office hours.

(10) Response Efficacy (RE)

- RE1: Telephone (audio) only is effective for solving remote ventilated patient management issues.
- RE2: Videoconferencing is effective for solving remote ventilated patient management issues.
- RE3: Videoconferencing will be more effective than telephone-only support in solving remote ventilated patient management issues.
  [adapted from Sun et al., 2013]

(11) Experience (E)

- E1: I have smartphone experience.
- E2: I have mechanical ventilator experience.
- E3: I have videoconferencing experience.

- E4: I have telephone (audio) only experience doing remote ventilated patient management with the AVC.

(12) Response Cost (RC)

- RC1: Smartphones are expensive to purchase.
- RC2: I already have a smartphone so videoconferencing will not cost me anymore.
- RC3: I will have to spend effort to learn how to use smartphone videoconferencing. [adapted from Sun et al., 2013]

(13) Social Influence/Norm (SIN)

- SIN1: People important to me think I should use smartphone videoconferencing in remote ventilated patient management.
- SIN2: People whose opinions I respect think I should use smartphone videoconferencing in remote ventilated patient management.
- SIN3: People who influence my behavior think I should use smartphone videoconferencing in remote ventilated patient management.
- SIN4: Clinicians think I should use smartphone videoconferencing in remote ventilated patient management.

(14) *Intent to Use* (IU)

- IU1: I intend to use smartphone videoconferencing as soon as it is available.
- IU2: I would use smartphone videoconferencing if I had a smartphone.
- IU3: I plan on using smartphone videoconferencing for remote ventilated patient management.

(15) Pre-Test Performed (PTP)

- PTP1: I would like to test my smartphone using videoconferencing.
- PTP2: The benefits of using smartphone videoconferencing for remote patient management are obvious.
- PTP3: I would like a demonstration of using smartphone videoconferencing for remote ventilated patient management.
- PTP4: It is NOT clear to me how videoconferencing can be used for remote ventilated patient management.

(16) Actual Behavior

- AB1: I have used videoconferencing on my smartphone.
- AB2: I use videoconferencing often.

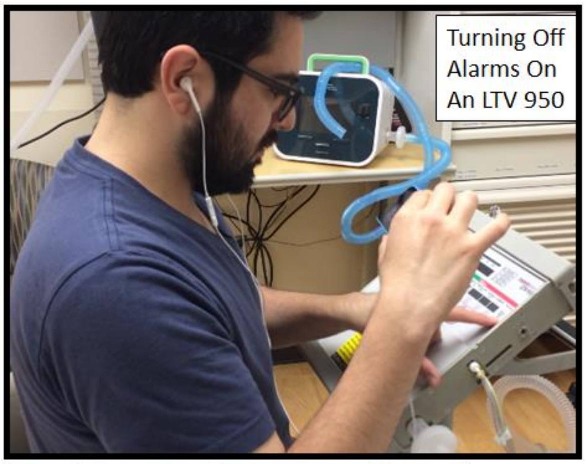
(17) Habit

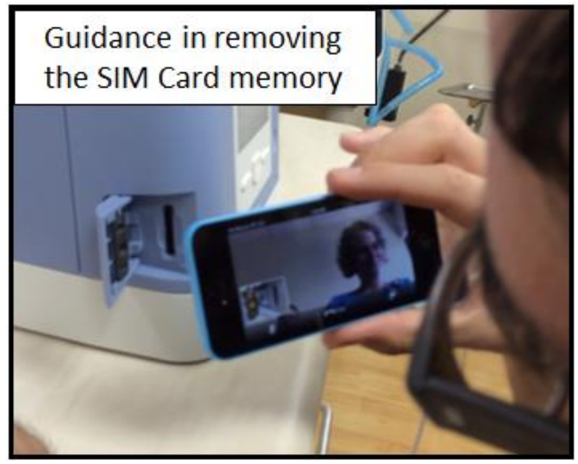
- H1: Using my smartphone has become a habit for me. [adapted from Yuan et al., 2015]
- H2: I am addicted to using my smartphone. [adapted from Yuan et al., 2015]
- H3: I use videoconferencing regularly. [adapted from Yuan et al., 2015]

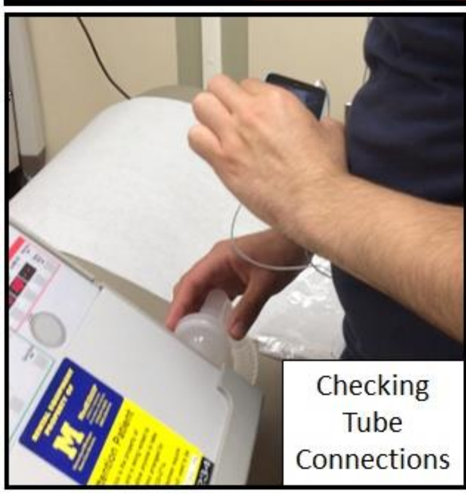
Appendix G: Final Questionnaire

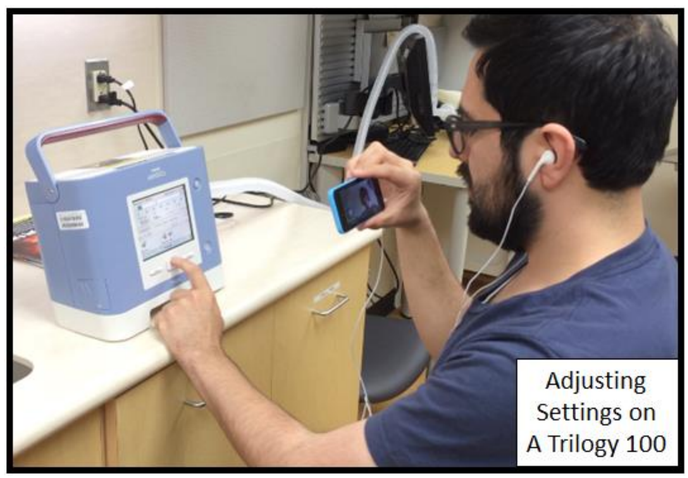
Assisted Ventilation Clinic (AVC): Telemedicine Questionnaire

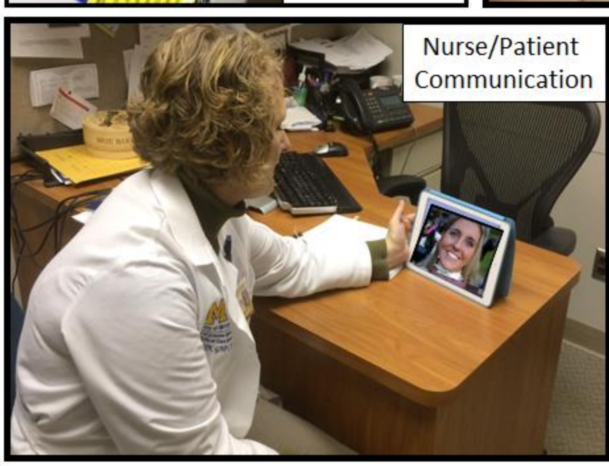
Clinicians (e.g. MDs, RNs, NPs, RTs) in the AVC using an iPad can communicate with patients and caregivers at home using their smartphones (e.g. iPhones or Android phones). The pictures below show some of the ways clinicians can guide patients and caregivers in providing care. We would like to find out what you think about smartphone videoconferencing for remote ventilated patient management by completing a questionnaire.

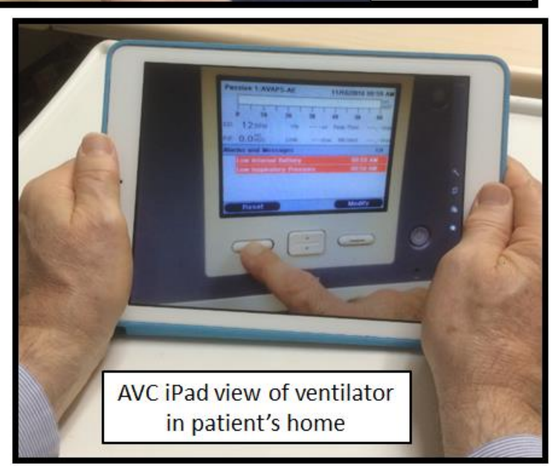












PULMONARY & CRITICAL CARE MEDICINE
A DIVISION OF INTERNAL MEDICINE
UNIVERSITY OF MICHIGAN HEALTH SYSTEM
& EASTERN MICHIGAN UNIVERSITY

Informed Consent to Participate in this Research Study

ASSESSING PATIENT AND CAREGIVER "INTENT TO USE" SMARTPHONE VIDEOCONFERENCING FOR REMOTE MECHANICALLY-VENTILATED PATIENT MANAGEMENT

(In other words, this study is about using smartphones, such as iPhones or Android phones, to care for ventilated patients at home)

Principal Investigator: Brian R. Smith, PhD Candidate, Eastern Michigan University
Faculty Advisor: Dr. Jeanette P. Brown, M.D., PhD, UMHS Assisted Ventilation Clinic
Co-investigators: Julie Hanley, NP; Armando Kurili, RT; and Kim Rochefort, RN - UMHS Assisted Ventilation Clinic

Brian R. Smith, a PhD Candidate at Eastern Michigan University, and the Assisted Ventilation Clinic (AVC) invite you to complete a questionnaire about patients' and caregivers' "intent to use" smartphones to remotely care for patients on mechanical ventilators. This activity is sometimes called telemedicine.

Study Description: There are 14 background questions about the patient or caregiver followed by 24 questions asking your opinion about telemedicine. Answers range from "(1) Strongly Disagree" to "(5) Strongly Agree".

Benefits: By completing this questionnaire, you will provide insight to the AVC in implementing telemedicine services.

Risks/Discomforts: The risks of this study are low. However, if you experience discomfort or side effects, you may stop at any time. We will discard any data entered and you may contact the AVC or your healthcare provider.

Compensation: You will not receive any money or anything else for completing the questionnaire. We are grateful to you for contributing your time and opinions.

Confidentiality: We will publish the results of this study but it will not include any information that could identify you. To keep your information safe, we use Qualtrics to collect and store your personal health information. The University of Michigan or government offices may need to examine the data to make sure the research is safe and proper.

Voluntary nature of the study: Completing this questionnaire is voluntary. If you change your mind, you may stop at any time. If you stop early, any data you entered up to that time will be discarded.

Contact Information: If you have any questions about this research, you may contact: Kim Rochefort, Dr. Jeanette Brown, Julie Hanley, or Armando Kurili at the Adult Assisted Ventilation Clinic, or Brian Smith (the Primary Investigator) at 734-545-9587 or brsmit@med.umich.edu .

If you have questions about your rights as a participant or other concerns, but don't want to talk to the researcher(s), please contact the University of Michigan Health Sciences and Behavioral Sciences Institutional Review Board, 2800 Plymouth Rd., Bldg. 520, Room 1169, Ann Arbor, MI 48109-2800, (734) 936-0933 or at irbhsbs@umich.edu.

Your Informed Consent: The answers you submit are completely anonymous – there are no connections between you and your responses. Make sure any questions you have are answered and you understand what you are being asked to do. Please contact the researchers if you have any more questions. **By fully completing this questionnaire, you are agreeing to participate in this study.**

NOTE: Smartphone definition: A mobile (cell) phone with a touchscreen display, internet access, email, text messaging, front and back cameras, and an operating system (e.g. iOS or Android) that allows it to download and use applications.

Please answer the following 14 background questions. Mark your answers by either putting an "X" through your selection* (e.g. ☒) *or entering number in the box* [ ] *when requested.

1) I am a: ☐Patient ☐Family/Friend Caregiver ☐Professional Caregiver (RN, RT, NP...)
2) Enter your age in number of years [ ]
3) Sex: ☐Male ☐Female
4) What type of disease/condition do you (or does the patient) have: …………………
   ☐ALS ☐SCI ☐DMD ☐CP ☐Myopathy ☐Muscular dystrophy ☐OSA ☐Other
5) What type of respiratory assist device(s) do you (or does the patient) use? ……………
   ☐CPAP ☐BiPAP ☐LTV ☐Trilogy ☐Astral ☐Cough Assist Device ☐Other
6) Approximately how many hours a day do you (or does the patient) use a ventilator?
   [ ]
7) Do you (or does the patient) have a "trach" (tracheostomy) tube? ☐YES ☐NO
8) Do you own or have access to a smartphone (e.g. iPhone or Android) between the hours of 8am - 5pm, Monday through Friday? ☐Yes ☐No
9) Have you ever used videoconferencing before (e.g. Skype, FaceTime)? ☐Yes ☐No
10) Have you ever downloaded applications on your smartphone? ☐Yes ☐No
11) Please select ALL of the types of devices that you own or have access:
    ☐Apple iPhone ☐Apple iPad ☐Android Smartphone ☐Android Tablet
    ☐Other Type of Phone or Tablet ☐Laptop Computer ☐Desktop Computer
12) Is there either cellular or WiFi internet access in the patient's home? ☐Yes ☐No
13) Approximately how many miles does the patient travel to the nearest emergency department (ED)? [ ]
14) Approximately how many miles does the patient travel to the UMHS Assisted Vent Clinic? [ ]

==

Please answer the following 24 questions based on your opinions. Answers range from **(1)Strongly Disagree** up to **(5)Strongly Agree**. There is no right or wrong answer, expressing your opinions is what is most important.

The following 24 questions are about using smartphones in caring for remote ventilated patients at home:

	Strongly 1 Disagree	2 Disagree	3 Neutral	4 Agree	Strongly 5 Agree
1. It will overall make caregiving easier…………...	☐	☐	☐	☐	☐
2. It will make interacting with clinicians easier.......	☐	☐	☐	☐	☐
3. It will provide better remote support…………..	☐	☐	☐	☐	☐
4. It will be easy for me to use…………………….	☐	☐	☐	☐	☐
5. I am able to use it……………………………..…	☐	☐	☐	☐	☐
6. I have experience using videoconferencing……...	☐	☐	☐	☐	☐
7. It is a good idea……………………………...…	☐	☐	☐	☐	☐
8. It is wise…………………………………………	☐	☐	☐	☐	☐
9. The benefits of using it are obvious……………...	☐	☐	☐	☐	☐
10. I can see the value in using it. ……….…………	☐	☐	☐	☐	☐
11. I need a demonstration of using it……………...	☐	☐	☐	☐	☐
12. It will be useful in caregiving……..………….....	☐	☐	☐	☐	☐
13. It will help solve problems more quickly………	☐	☐	☐	☐	☐
14. It will help make caregivers more effective……	☐	☐	☐	☐	☐
15. It will take time to learn…..……………………..	☐	☐	☐	☐	☐
16. It is expensive…………………………………..	☐	☐	☐	☐	☐
17. I will need support in using it………………..…	☐	☐	☐	☐	☐
18. People important to me think I should use it…..	☐	☐	☐	☐	☐
19. People whose opinions I respect think I should use it. ……………………………………………………..	☐	☐	☐	☐	☐
20. People who influence me think I should use it…	☐	☐	☐	☐	☐

Mechanically-ventilated patients are:

	Strongly 1 Disagree	2 Disagree	3 Neutral	4 Agree	Strongly 5 Agree
21. Vulnerable to equipment failures, alarms, or incorrect settings (e.g. ventilators, cough assist devices) ……. ……………………	☐	☐	☐	☐	☐
22. Susceptible to medical emergencies (e.g. infections, mucus buildup) …………………………………………..	☐	☐	☐	☐	☐
23. At risk of serious issues that require immediate medical attention	☐	☐	☐	☐	☐

24. ***If you own or have access to a smartphone, answer question "A".***
If you DO NOT own and DO NOT have access to a smartphone, answer question "B":

	1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree
A. (I **<u>Own</u>** or **<u>Have Access</u>**) **I plan on using a smartphone for remote mechanically-ventilated patient management?**	☐	☐	☐	☐	☐
B. (I **<u>Do Not</u>** Own/**<u>No</u>** Access) **However, if I did own or have access to a smartphone, I would use it for remote mechanically-ventilated patient management**. …………………………………………	☐	☐	☐	☐	☐

============================

If you still want to submit your answers, please return this completed questionnaire to the person who gave it to you. Thank You!

Appendix H: Remote Ventilated Patient Population Characteristics

- Distance from Clinic – Close to Hours away, few miles to 100s of miles away
- Distance from Adult Ventilation Clinic
- Diseases – Many Different Types of Diseases
- Time on Ventilator
- Tracheostomy (invasive or non-invasive)
- Two or more caregivers per patient
- Life Critical Care – High Risk
- Mobile Devices used in Clinic (Tablet) and Apple/Android smartphones/tablets
- Other Technology – Cough Assist Device, Mechanical Ventilator
- Alternatives: Telephone-Only Support, Patient to emergency department, Patient to AVC, RT to Patient's Home, Videoconferencing
- D - Age
- D – Gender
- Education – Different Levels; Education/Training Level – Nurse, Family, Hrs of training, Past Experience
- Patient and Caregiver Training and Experience – Different Levels
- Travel Difficult – may be like moving a small refrigerator
- Complex Care – uncertainty
- Voluntariness – Different Levels
- Knowledge – Different Levels
- Alarms – Could be major problems
- Behavioral Control – Patient (0% to 100% Dependent); Caregivers (Confidence, Experience, many factors)
- Trialability – Test to see if better
- Skills – like experience – different levels
- Mobile Devices – Past Experience/ Have they used them before?
- Videoconferenced before? Past behavior?
- Ventilator vs. Mobile Device VC – trade-off of technology complexity
- Patient Conditions vs. Mobile Device VC – trade-off ability to diagnose vs. remote diagnosis
- VC Faster?
- VC reduce care burden?
- Technology – what MobDevs do they have?
- Barriers (Cost, Inexperience, Privacy, Security, Bandwidth)
- Testability – Are they willing to do a pre-test
- Demonstrability – Willing to see if better?
- Tech Problems – Are they worried about tech not working? Quality good enough?
- Job Relevance – help them be more efficient in caregiving?
- Quality of Experience?
- Severity, Susceptibility, Vulnerability, Seriousness of patient state
- Will they Test – Feedback? Good or Bad?
- Do they Intend to Use?
- Any Anxiety about Patient? Vs. Using VC? Vs. Ventilator? Vs. Cough Assist Device?
- Attitude, Motivation, Emotions, Trust, Awareness, Consciousness, Risk
- Ext Influences – Caregivers, Family, Patients, Clincians, Peers, Social Influence, Voluntariness
- How Long Owned or Used Smartphone/Tablet?
- Confidence in Caring for Patient?
- Years on Ventilator
- Telephone-Only versus Videoconferencing
- Used Skype or FaceTime before?
- Effort Expectancy – VC worth the effort

Appendix I: EMU and U of M IRB Approval Letters

RESEARCH @ EMU

UHSRC Determination: **EXEMPT**

DATE: **November 17, 2016**

TO: **Brian Smith, MS**
Eastern Michigan University

Re: **UHSRC: # 953511-1**
Category: Exempt category 2
Approval Date: November 17, 2016

Title: **Assessing Patient and Caregiver "Intent to Use" Smartphone Videoconferencing for Remote Mechanically Ventilated Patient Management**

Your research project, entitled **Assessing Patient and Caregiver "Intent to Use" Smartphone Videoconferencing for Remote Mechanically Ventilated Patient Management,** has been determined **Exempt** in accordance with federal regulation 45 CFR 46.102. UHSRC policy states that you, as the Principal Investigator, are responsible for protecting the rights and welfare of your research subjects and conducting your research as described in your protocol.

Renewals: Exempt protocols do not need to be renewed. When the project is completed, please submit the **Human Subjects Study Completion Form** (access through IRBNet on the UHSRC website).

Modifications: You may make minor changes (e.g., study staff changes, sample size changes, contact information changes, etc.) without submitting for review. However, if you plan to make changes that alter study design or any study instruments, you must submit a **Human Subjects Approval Request Form** and obtain approval prior to implementation. The form is available through IRBNet on the UHSRC website.

Problems: All major deviations from the reviewed protocol, unanticipated problems, adverse events, subject complaints, or other problems that may increase the risk to human subjects **or** change the category of review must be reported to the UHSRC via an **Event Report** form, available through IRBNet on the UHSRC website

Follow-up: If your Exempt project is not completed and closed after **three years**, the UHSRC office will contact you regarding the status of the project.

Please use the UHSRC number listed above on any forms submitted that relate to this project, or on any correspondence with the UHSRC office.

Good luck in your research. If we can be of further assistance, please contact us at 734-487-3090 or via e-mail at human.subjects@emich.edu. Thank you for your cooperation.

Sincerely,

Jennifer Kellman Fritz, PhD
Chair
University Human Subjects Review Committee

From: eresearch@umich.edu [mailto:eresearch@umich.edu]
Sent: Tuesday, October 18, 2016 10:47 AM
To: Brown, Jeanette; brsmit@umich.edu; krochefo@umich.edu
Subject: eResearch Notification: Notice of Exemption for (HUM00117894)

UNIVERSITY OF MICHIGAN
eResearch.umich.edu

Medical School Institutional Review Board (IRBMED) • 2800 Plymouth Road, Building 520, Suite 3214, Ann Arbor, MI 48109-2800 • phone (734) 763 4768 • fax (734) 763 9603 • irbmed@umich.edu

---

To: Brian Smith
From:

Michael	Geisser
Alan	Sugar

Cc:

Jeanette	Brown
Armando	Kurili
Brian	Smith
Julie	Hanley
Kimberly	Rochefort

Subject: Notice of Exemption for [HUM00117894]

SUBMISSION INFORMATION:
Title: Intent to Use Smartphone Videoconferencing for Remote Mechanically Ventilated Patients
Full Study Title (if applicable): Patient and Caregiver "Intent to Use" Smartphone Videoconferencing for Remote Mechanically Ventilated Patient Management
Study eResearch ID: HUM00117894
Date of this Notification from IRB: 10/18/2016
Date of IRB Exempt Determination: 10/18/2016
UM Federalwide Assurance: FWA00004969 (For the current FWA expiration date, please visit the UM HRPP Webpage)

IRB EXEMPTION STATUS:
The IRBMED has reviewed the study referenced above and determined that, as currently described, it is exempt from ongoing IRB review, per the following federal exemption category:

EXEMPTION #2 of the 45 CFR 46.101.(b):
Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.
Note that the study is considered exempt as long as any changes to the use of human subjects (including their data) remain within the scope of the exemption category above. Any proposed changes that may exceed the scope of this category, or the approval conditions of any other non-IRB reviewing committees, must be submitted as an amendment through eResearch.
Although an exemption determination eliminates the need for ongoing IRB review and approval, you still have an obligation to understand and abide by generally accepted principles of responsible and

ethical conduct of research. Examples of these principles can be found in the Belmont Report as well as in guidance from professional societies and scientific organizations.

PRIVACY BOARD REVIEW:

The Privacy Board has reviewed the project referenced above and has granted a Waiver of HIPAA Authorization. The Privacy Board has determined that the proposed project conforms with applicable regulations and policies. This project must be conducted in accordance with the description and information provided in the application and associated documents.

Note: This project is regulated under the HIPAA Privacy Rule, which requires you to account for certain disclosures of Protected Health Information (PHI).

SUBMITTING AMENDMENTS VIA eRESEARCH:

You can access the online forms for amendments in the eResearch workspace for this exempt study, referenced above.

ACCESSING EXEMPT STUDIES IN eRESEARCH:

Click the "Exempt and Not Regulated" tab in your eResearch home workspace to access this exempt study.

Michael Geisser
Co-chair, IRBMED

Alan Sugar
Co-chair, IRBMED

Appendix J: Pilot Questionnaire

Adult Assisted Ventilation Clinic (AVC): Pilot Telemedicine Questionnaire

Thank you for agreeing to complete this pilot questionnaire and providing constructive feedback. Our goals are to make sure the directions are clear and the questions are easy to understand. At the end, you will be asked six opinion questions about the questionnaire. There is also a text box where you can enter any suggestions for improvement. Please put your starting and ending times in the boxes when asked.

Before you begin completing the questionnaire, enter your starting time in the following box

[   ]

A DIVISION OF INTERNAL MEDICINE PULMONARY & CRITICAL CARE MEDICINE UNIVERSITY OF MICHIGAN HEALTH SYSTEM & EASTERN MICHIGAN UNIVERSITY

Adult Assisted Ventilation Clinic (AVC): Telemedicine Questionnaire

Thank you for considering participating in this study. Please read the informed consent on this page and review the telemedicine pictures on the other side. If you decide to complete the questionnaire, you will be asked to complete 14 background questions and 24 questions asking your opinion about using smartphones in caring for ventilated patients at home. Opinion questions are rated from **(1) Strongly Disagree** to **(5) Strongly Agree**. Your participation is greatly appreciated!

Informed Consent to Participate in this Research Study

ASSESSING PATIENT AND CAREGIVER "INTENT TO USE" SMARTPHONE VIDEOCONFERENCING FOR REMOTE MECHANICALLY-VENTILATED PATIENT MANAGEMENT

(In other words, this study is about using smartphones, such as iPhones or Android phones, to care for ventilated patients at home)

Principal Investigator: Brian R. Smith, PhD Candidate, Eastern Michigan University
Faculty Advisor: Dr. Jeanette P. Brown, M.D., PhD, UMHS Assisted Ventilation Clinic
Co-investigators: Julie Hanley, NP; Armando Kurili, RT; and Kim Rochefort, RN - UMHS Assisted Ventilation Clinic

Brian R. Smith, a PhD Candidate at Eastern Michigan University, and the Assisted Ventilation Clinic (AVC) invite you to complete a questionnaire about patients' and caregivers' "intent to use" smartphones to remotely care for patients on mechanical ventilators. This activity is sometimes called telemedicine.

Study Description: There are 14 background questions about the patient or caregiver followed by 24 questions asking your opinion about telemedicine. Answers range from "(1) Strongly Disagree" to "(5) Strongly Agree".

Benefits: By completing this questionnaire, you will provide insight to the AVC in implementing telemedicine services.

Risks/Discomforts: The risks of this study are low. However, if you experience discomfort or side effects, you may stop at any time. We will discard your data and you may contact the AVC or your healthcare provider.

Compensation: You will not receive any money or anything else for completing the questionnaire. We are grateful to you for contributing your time and opinions.

Confidentiality: We will publish the results of this study but it will not include any information that could identify you. To keep your information safe, we use Qualtrics to collect and store your personal health information. The University of Michigan or government offices may need to examine the data to make sure the research is safe and proper.

Voluntary nature of the study: Completing this questionnaire is voluntary. If you change your mind, you may stop at any time. If you stop early, any data you entered up to that time will be discarded.

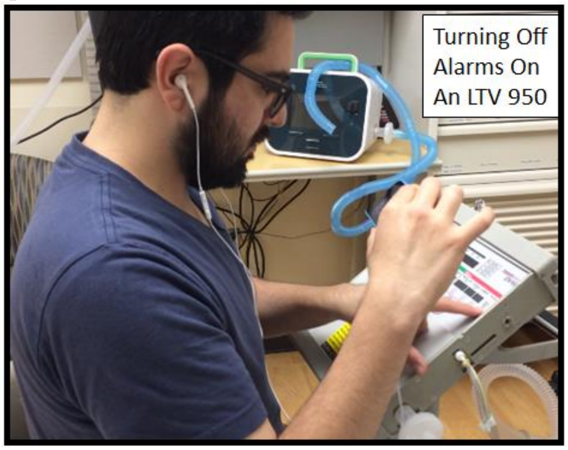
Contact Information: If you have any questions about this research, you may contact: Kim Rochefort, Dr. Jeanette Brown, Julie Hanley, or Armando Kurili at the Adult Assisted Ventilation Clinic, or Brian Smith (the Primary Investigator) at 734-545-9587 or brsmit@med.umich.edu .

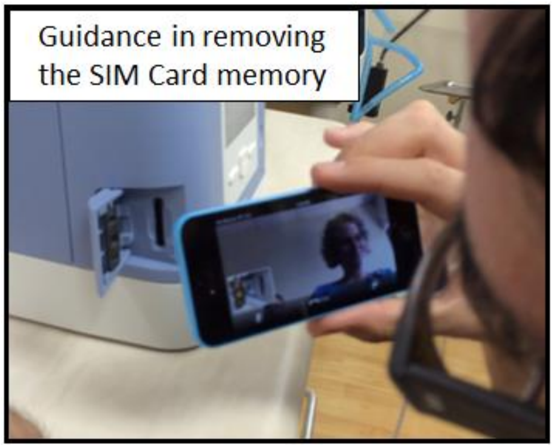
If you have questions about your rights as a participant or other concerns, but don't want to talk to the researcher(s), please contact the University of Michigan Health Sciences and Behavioral Sciences Institutional Review Board, 2800 Plymouth Rd., Bldg. 520, Room 1169, Ann Arbor, MI 48109-2800, (734) 936-0933 or at irbhsbs@umich.edu.

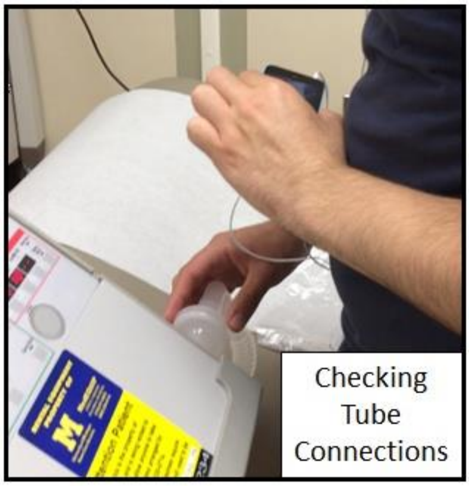
Your Informed Consent: The answers you submit are completely anonymous – there are no connections between you and your responses. Make sure any questions you have are answered and you understand what you are being asked to do. Please contact the researchers if you have any more questions. **By fully completing this questionnaire, you are agreeing to participate in this study.**

Assisted Ventilation Clinic (AVC) Questionnaire:

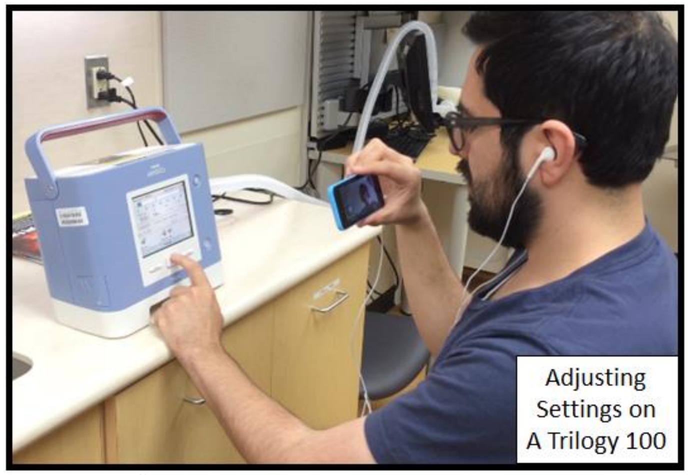
Using smartphones (e.g. iPhones or Android phones), clinicians (e.g. nurses, respiratory therapists, and doctors) in the AVC can communicate with remote patients and their caregivers at home. Using the picture camera on the back of the patient's or caregiver's phone, the clinicians can see and guide caregivers in solving problems as shown in the following pictures. We would like to find out what you think about using smartphone videoconferencing for remote ventilated patient management by completing this questionnaire.



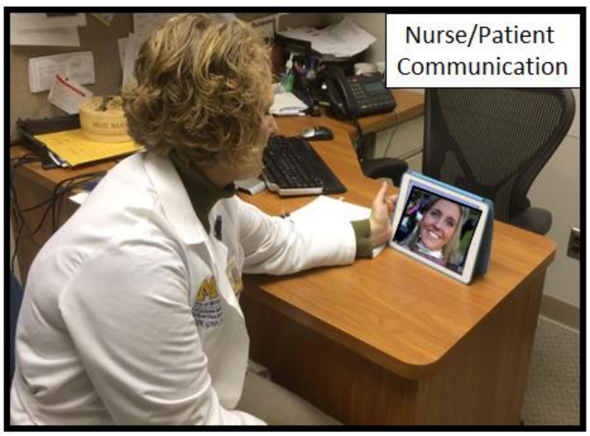




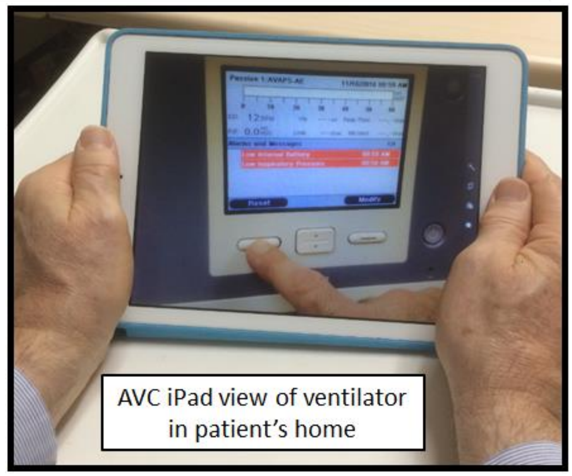
Checking Tube Connections



Adjusting Settings on A Trilogy 100



Nurse/Patient Communication



AVC iPad view of ventilator in patient's home

Please answer the following 14 background questions. Mark your answer by putting an "X" through the box you are selecting* (e.g. ☒) *and enter numbers in* [ ] *boxes.

15) I am a: ☐Patient ☐Family/Friend Caregiver ☐Professional Caregiver (RN, RT, NP...)

16) Enter your age in number of years [ ]

17) Sex: ☐Male ☐Female

18) What type of disease/condition do you (or the patient) have: ………………………
☐ALS ☐SCI ☐DMD ☐CP ☐Myopathy ☐Muscular dystrophy ☐OSA ☐Other

19) What type of respiratory assist device(s) do you (or the patient) use? ……………
☐CPAP ☐BiPAP ☐LTV ☐Trilogy ☐Astral ☐Cough Assist Device ☐Other

20) Approximately how many hours a day do you (or does the patient) use a ventilator? [ ]

21) Do you (or does the patient) have a "trach" (tracheostomy) tube? ☐YES ☐NO

22) Do you own or have access to a smartphone (e.g. iPhone or Android) between the hours of 8am - 5pm, Monday through Friday? ☐Yes ☐No

23) Have you ever used videoconferencing before (e.g. Skype, FaceTime)? ☐Yes ☐No

24) Have you ever downloaded applications on your smartphone? ☐Yes ☐No

25) Please select ALL of the types of devices that you own or have access:
☐Apple Smartphone ☐Apple Tablet ☐Android Smartphone ☐Android Tablet
☐Other Type of Phone or Tablet ☐Laptop Computer ☐Desktop Computer

26) Is there either cellular or WiFi internet access in the patient's home? ☐Yes ☐No

27) Approximately how many miles does the patient travel to the nearest emergency department (ED)? [ ]

28) Approximately how many miles does the patient travel to the UMHS Assisted Vent Clinic? [ ]

===

Please answer the following 24 questions based on your opinions. Answers range from **(1)Strongly Disagree** up to **(5)Strongly Agree**. There is no right or wrong answer, expressing your opinions is what is most important.

The following 24 questions are about using smartphones in caring for remote ventilated patients at home:

	1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree
1. It will overall make caregiving easier…………...	☐	☐	☐	☐	☐
2. It will make interacting with clinicians easier.......	☐	☐	☐	☐	☐
3. It will provide better remote support…………..	☐	☐	☐	☐	☐
4. It will be easy for me to use…………………….	☐	☐	☐	☐	☐
5. I am able to use it…………………………...….	☐	☐	☐	☐	☐
6. I have experience using videoconferencing……...	☐	☐	☐	☐	☐
7. It is a good idea……………………………..….	☐	☐	☐	☐	☐
8. It is wise……………………………………….	☐	☐	☐	☐	☐
9. The benefits of using it are obvious……………...	☐	☐	☐	☐	☐
10. I can see the value in using it. ………….………	☐	☐	☐	☐	☐
11. I need a demonstration of using it……………...	☐	☐	☐	☐	☐
12. It will be useful in caregiving……..……………....	☐	☐	☐	☐	☐
13. It will help solve problems more quickly………	☐	☐	☐	☐	☐
14. It will help make caregivers more effective……	☐	☐	☐	☐	☐
15. It will take time to learn……….………………..	☐	☐	☐	☐	☐
16. It is expensive………………………………..	☐	☐	☐	☐	☐
17. I will need support in using it………………..…	☐	☐	☐	☐	☐
18. People important to me think I should use it…..	☐	☐	☐	☐	☐
19. People whose opinions I respect think I should use it. ………………………………………………………..	☐	☐	☐	☐	☐
20. People who influence me think I should use it…	☐	☐	☐	☐	☐

Mechanically-ventilated patients are:

	Strongly 1 Disagree	2 Disagree	3 Neutral	4 Agree	Strongly 5 Agree
21. Vulnerable to equipment failures, alarms, or incorrect settings (e.g. ventilators, cough assist devices) ……. ……………………	☐	☐	☐	☐	☐
22. Susceptible to medical emergencies (e.g. infections, mucus buildup) …………………………………………..	☐	☐	☐	☐	☐
23. At risk of serious issues that require immediate medical attention	☐	☐	☐	☐	☐

24. ***If you own or have access to a smartphone, answer question "A".***
If you DO NOT own and DO NOT have access to a smartphone, answer question "B":

	Strongly 1 Disagree	2 Disagree	3 Neutral	4 Agree	Strongly 5 Agree
A. (I **Own** or **Have Access**) **I plan on using a smartphone for remote mechanically-ventilated patient management?**	☐	☐	☐	☐	☐
B. (I **Do Not** Own/**No** Access) **However, if I did own or have access to a smartphone, I would use it for remote mechanically-ventilated patient management**. ………………………………………….	☐	☐	☐	☐	☐

===========================

If you still want to submit your answers, please return this completed questionnaire to the person who gave it to you. Thank You!

Pilot Participants – please continue …

Pilot participants*, you have completed the questionnaire, please enter your ending time in this box* [ ]

Pilot Questionnaire Feedback:

	Strongly 1 Disagree	2 Disagree	3 Neutral	4 Agree	Strongly 5 Agree
1. The time to complete the questionnaire is too long…..	☐	☐	☐	☐	☐
2. There are too many questions ..………………….......	☐	☐	☐	☐	☐
3. The questions are easy to understand…………………	☐	☐	☐	☐	☐
4. The questionnaire questions are confusing. ……….....	☐	☐	☐	☐	☐
5. The questionnaire directions are not clear…………….	☐	☐	☐	☐	☐
6. The words used are understandable…………………..	☐	☐	☐	☐	☐…

Please enter any additional suggestions for improving the questionnaire in the following box:

Thank you for providing Pilot Questionnaire Feedback for this Smartphone Videoconferencing Study.

Appendix K: Extracted Five Factor Structural Equation Model Path Diagram