GeoICT for Meeting the Needs of Remote Patient Monitoring and Healthcare

Tripathi, S.
Albert Einstein College of Medicine, New York, USA, E-mail: stripat1@mail.einstein.yu.edu

Abstract
Spatial Accessibility, a metric that combines medical resource availability and geographic accessibility, is a key determinant of healthcare access. It affects urban and rural patients and negatively impacts care-seeking, follow-up post-discharge, health literacy, and chronic disease management. Current and emerging Telehealth and Remote Patient Monitoring (RPM) platforms are ideal for patients with significant barriers to spatial accessibility, due to the versatility and adaptability of their modular designs. This review will (a) characterize negative impacts of barriers to spatial accessibility and (b) demonstrate potential and current capabilities of telehealth and RPM in mitigating many of these challenges, focusing on streamlining patient discharge from the hospital, improving patient and family health literacy, and supporting chronic disease management.

1. Spatial Accessibility - A Key Determinant of Healthcare Access

Access to healthcare is multifaceted and has many definitions. One formulation, proposed in 1992 by the Institute of Medicine, defined Healthcare Access as the "timely use of personal health services to achieve the best possible health outcomes"(Services I of M (US) C on MA to PHC, Millman M. A Model for Monitoring Access, 1993). At the time, the presence of healthcare providers, insurance coverage, and encounters with healthcare providers were the sole markers of healthcare access. Understanding of healthcare barriers has evolved much since then. Proximity to healthcare access points or having adequate medical insurance does not guarantee access. Conversely, many people with neither easily reachable doctors nor health insurance will opt for informal healthcare settings. The timely use of personal health services, healthcare access, has three dimensions: spatial accessibility, affordability and acceptability (Baig et al., 2017) (Figure 1). Spatial accessibility combines availability and geographic accessibility. Availability, per this formulation, includes the number of local, desirable healthcare access points, waiting times, and the quality of available services. Each of these factors covers different challenges faced by patients and service-providers. Geographic accessibility derives from location of households and medical services and transportation options or travel time to reach these access points. In settings with high numbers of healthcare access options, availability and accessibility become inter-dependent. This inter-dependence is expressed as the combined variable of spatial accessibility (Guagliardo et al., 2004). Patients may be "remote" because they are far away from existing healthcare access points or unable to travel to them due to financial, geographical, or transportation limitations. Patients may be unable to access care due to lack of tele-based or online system in many hospitals, urban or rural.

2. Geographic Information Systems to End the Urban-Rural Dichotomy

Remoteness and Spatial Accessibility are not restricted to rural or urban settings. Multiple studies show the negative impact of distance and transportation options upon healthcare utilization in urban areas and by the lower provider-to-patient ratios in rural and frontier areas (Giger et al., 2015, Syed et al., 2013, Thaddeus and Maine, 1994, Feikin et al., 2009 and O'Donnell, 2007). However, understanding Spatial Accessibility requires eschewing the urban-rural dichotomy that erroneously guides policy makers towards binary decision making for the allocation of healthcare resources. Healthcare policy aimed at improving access targets rural and urban areas, even though data suggest that policymakers would do well to analyze sub-clusters within these areas and tailor policies to them. Spatial Accessibility is a critical issue for both urban and rural populations (Table 1). Studies conducted in rural areas tend to identify increasing distance to healthcare providers as predictors of worsening outcomes. Meanwhile, those conducted in urban settings showed worse outcomes for patients with limited transportation and physical barriers to accessing healthcare. In urban studies, socioeconomic factors show strong interplay with spatial accessibility and inform the

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discrepancy in transportation options between patients in the same cities. Mapping is an essential epidemiological tool; perhaps the first prominent evidence of this was the case of the London Cholera outbreak of 1854, where mapping of cholera cases around 13 water pumps allowed epidemiologists to pinpoint and remove the disease-spreading pump. Today, Geographic Information Systems (GIS) can guide policy regarding disease surveillance, resource allocation, and analysis of existing services in urban and rural subclusters (Fradelos et al., 2014).

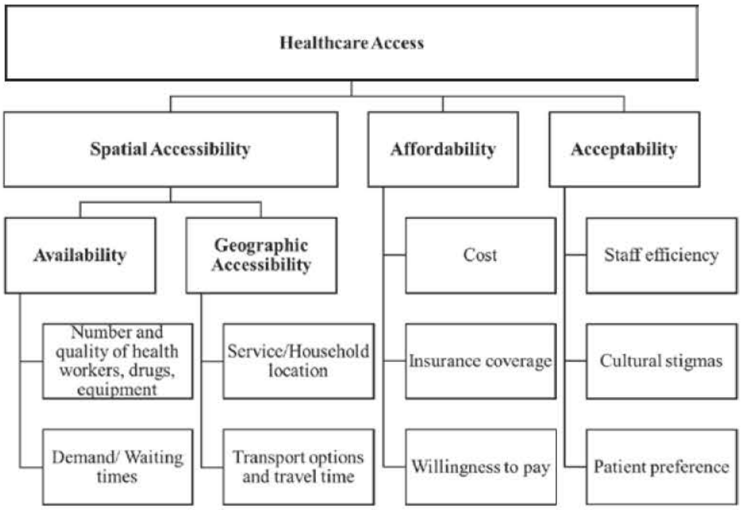

Figure 1: Healthcare access combines spatial accessibility, affordability, and acceptability.

Table 1: Distance to provider, transportation options, and travel time negatively impact spatial accessibility among urban and rural populations. Summary results for studies in urban and rural areas from several countries and for a wide-range of patient populations are provided

Study	Year	Country	Setting	Population	Results
Feikin et al.,	2009	Kenya	Rural	2432, ≤5yo Pediatric	Rate of clinic visits decreased linearly at 34% (95% CI, 31%-37%) per km after 0.5 km and up to 4 km from nearest clinic.
Kenny et al.	2015	Liberia	Rural	600, ≥17yo Females	Inverse relationships between distance to the nearest health facility and maternal health services uptake, facility deliveries, and health care seeking for most child health indicators.
Kyei et al.	2012	Zambia	Rural	7146, 15–49yo Females	For each 10 km increase in distance, the odds of women receiving antenatal care (ANC) decreased 25%. Each increase in the level of provision category of the closest facility was associated with a 54% increase in the odds of receiving ANC.
Gallagher et al.	2011	Ireland/ Northern Ireland	Rural/ Urban	121 urban and rural dwelling adults with age-related vision impairment, Median age 70yo	Public transport options are not accessible to those with vision impairment. While costlier transport options (taxis, personal drivers, etc.) exist, many participants reported financial constraints. Lack of access to public transport was a healthcare access issue for both urban and rural participants.
Shah et al.	2016	Canada	Urban	Geospatial analysis of 14 consensus metropolitan areas (cities with at least 100,000 population)	Spatial accessibility issues colocalize with urban neighborhoods further disadvantaged in the form of high health care needs, lower literacy rates, etc. These neighborhoods cluster around the downtown area and in the periphery of major Canadian cities.
Guidry et al.	1997	USA	Urban	593, ≥17yo Cancer patients	55 percent of African American and 60 percent of Hispanic survey respondents reported that transportation was a major barrier to treatment, compared to 38 percent of white respondents.
Guagliardo et al.	2004	USA	Urban	All Primary care providers for children (PCPC) in Washington DC	Washington DC found to have elevated supply of PCPCs compared to the national average, but large areas with largely African American populations fell far below the standards for PCPC accessibility, measured compositely as distance, transportation options, etc.

Mapping disease distribution, movement, and allocation of resources in areas of interest would give greater insights than simply dichotomizing areas as urban vs rural. Often, policy follows county and zip-code levels, but these are arbitrary boundaries that have little or no relevance to the spread of disease and the presence of relevant exposures. Spatial analyses in this case can guide the discovery of previously unknown associations. The challenge here is to overcome the lack of precise data regarding the spatial distribution of disease, due in part to concerns on patient privacy protection. However, decreasing spatial resolution to some degree and aggregating cases into clusters may sufficiently protect privacy. Yet another challenge is that GIS maps must be updated periodically with locations of available health services and disease incidence and prevalence information for them to be useful in real-time decision making. However, mapping has been used to identify areas with expanding patient populations and inadequate localized services. GIS systems have guided the implementation of telehealth and Remote Patient Monitoring (RPM) initiatives, in order to target areas with greater or emerging need (Soares et al., 2013). This is a significant public health undertaking but policy-makers would benefit from a model that goes beyond arbitrary dichotomies and demarcations towards a more predictive and evidence-based framework.

Distance, transportation costs, travel time, and primary care provider opportunity costs de-incentivize health care seeking and utilization for a wide range of health conditions. These factors are impedances to spatial accessibility. As shown in studies from urban and rural areas (Table 1), worsening health outcomes require a multidisciplinary solution. The increasing availability and decreasing cost of wireless technology and RPM systems provide an opportunity to address many of the factors impacting spatial accessibility. RPM's growth as a digital medicine tool reflects the diversity of platforms available for a variety of conditions (Table 2), and its growing market (Remote Patient Monitoring Market Size, Research & Growth, 2017) (projected to be USD 2.1 billion by 2022 from USD 703 million in 2015). RPM's versatility stems from its modular structure, through which healthcare professionals may design platforms ideally suited to the changing needs of the populations they serve.

3. Remote Patient Monitoring – Need of a Versatile Tool for Better Healthcare Access

RPM platforms follow a are combinations of the following core modules:

1) **Sensors** that measure physiological or environmental parameter of interest.
2) **Local or cloud based data storage** and processing unit that enables collection and rudimentary analysis for the removal of noise or prediction of programmable outcomes.
3) **Connection** between local data storage and central repository.
4) **Central data repository** for collection and rapid retrieval by analysis software.
5) **Software applications** that allow efficient, large-scale processing with minimal delays.

Adaptability is at the core of RPM. The options for each module growing array of options for each module: wearable or static sensors, local data storage or cloud-based computing, and wireless or hard-wired data connectivity. These options have sparked interest among health professionals representing many specialties. Sensors, particularly wearable sensors, have sparked a growing number of clinical trials and industry investments. Wearable sensors have a distinct advantage over competitor sensor technologies due to their interactive nature and capacity for continuous, non-invasive monitoring. Interactivity and wireless connectivity are two of the most important determinants of the overall success or failure of RPM initiatives (Baig et al., 2017). RPM relies on patient interaction and wearable sensors offer a greater degree of patient participation. Wearable sensors are key to helping patients interact with their own healthcare. Aside from wearables, sensors exist for prosthetics, walking canes, and sleeping surface to provide data on motor function, mobility, and sleep quality (Gashgari et al., 2016 and Gheorghiu and Ratchford, 2015). Wearable and static sensors for the recording of weight, blood sugar, and blood pressure, among others, are already seeing use in medical practices (Vegesna et al., 2017 and Varma and Pietro, 2015). Available for a wide range of purposes (Table 2) these sensors capture biopotential, motion, and environmental data for a wide range of use-cases.

Patients with chronic cardiac, respiratory, metabolic, and neurologic conditions all may benefit from RPM. In addition to improving spatial accessibility, on-site processing units coupled with these sensors allow prediction and prevention of adverse events like falls, myocardial infarctions, and seizures. In areas with greater wireless connectivity, cloud-based prediction platforms also assist with similar application (Mohammed et al., 2014 and Lan et al., 2012).

Table 2: Available sensor types measure biopotential, motion, and environmental data. These serve to assist patients and physicians to remotely coordinate and monitor a variety of conditions that would otherwise demand extensive utilization of on-site medical services (Baig et al., 2017, Gashgari et al., 2016, Gheorghiu and Varma and Pietro Ratchford, 2015 and Bashi et al., 2017)

Sensor	Sample Application
Biopotential Specific	
- Electrocardiogram (ECG)	Arrhythmias, Congestive heart failure, other chronic heart diseases
- Electromyography (EMG)	Neuromuscular diseases, Rehabilitation, Monitoring of prosthetics
- Electroencephalography (EEG)	Epilepsy, Sleep disorders, Brain death
Motion Sensor Units	
- Accelerometers	Gait, Fall-risk analysis, Activity monitoring
- Gyroscopes	Gait, Fall-risk analysis, Activity monitoring
Environmental Sensor	
- Video cameras	Gait, Fall-risk analysis
- Heart rate	Fitness trackers
- Heart Sound	Chronic heart conditions
- Pulse	Fitness trackers
- Pulse oximeters	Chronic obstructive pulmonary disease, Obstructive sleep apnea, Chronic heart conditions
- Temperature	Infertility
- Pressure sensors	Congestive Heart Failure, Hypertension, Diabetes
- Weight	Weight Management in metabolic disorders, Hypertension, etc.
- Blood glucose	Diabetes

3.1 RPM and Telehealth Solutions for Transportation Access, Healthcare Literacy, and Chronic Disease Management

3.1.1Mitigating transportation access issues

Transportation is a key determinant spatial accessibility, particularly in urban areas. The economically disadvantaged experience greater transportation difficulties, which prevent patients from being discharged (Ahmed et al., 2001), from continuing treatments after setting up care (Guidry, 2017) and from maintaining long-term follow up with primary care providers and specialists (Wheeler et al., 2007). Particularly affected are low-income suburbanites, who are less likely to own cars or other forms of automated personal transport than others (Silver et al., 2012). Transportation (59%) ranked ahead of "inability to afford the visit" (34%) and "lack of health insurance" (24%) among low-income, predominantly African-American patients interviewed prior to discharge in one study conducted to determine potential obstacles to post discharge follow-up for hospitalized diabetes patients (Wheeler et al., 2007). In spite of this, 95% of the responders in this study indicated that they intended to use follow-up services, which signals transportation access as a critical target for healthcare policy-makers.

The impact of transportation is felt acutely by patients requiring follow-up visits in the post-discharge period. These challenges lead to "rescheduled or missed appointments, delayed care, and missed or delayed medication use" (Wheeler et al., 2007) and these patients face poor long-term management and worse outcomes. Diabetes, Heart Failure, and Cancer patients are among those requiring strict follow-up in the transition post-discharge period. RPM can help transition complex chronic disease patients from the hospital back to the home setting while reducing risk for re-admission and relapse. In a 2015 study by Davis et al., 2015, the group studied the readmission rates at 30, 90, and 180 days post-discharge among COPD and Heart Failure patients. The COPD patients were monitored with pulse oximetry and heart rate, while the heart failure patients were monitored with body-weight. In addition to this, the platform included a preprogrammed, bilingual questionnaire targeting symptomatology. Acute changes in measured data or reported symptoms triggered a phone call to advise patients on further management. The mobile health intervention was accompanied with home-visits at scheduled intervals. The study reported up to 50% decrease in readmission rates at the 30-day interval and up to 18% decrease at the 180 day interval. Such an effect has the potential to mitigate the personal, financial, and institutional costs of acute rehospitalization.

3.1.2 Promoting health literacy in patients and their families

Remote Monitoring initiatives often share a common feature: longitudinal, focused patient education (Vegesna et al., 2017, Bashi et al., 2017, Davis et al., 2015, Block et al., 2016 see the reference list) and Cox et al., 2017). These education programs begin with familiarizing patients with the RPM platform and the details of the program. This is often followed up with discussing common signs of symptom exacerbation, proper management, and what to do in case of emergencies. Many studies will repeat these sessions with patients at set intervals within the follow-up period. Higher frequency training sessions are needed to familiarize patients with the RPM platform they will be using; this becomes especially crucial for patients living in areas with limited connectivity or those encountering problems in signal quality for other reasons. Patient education related to the disease process itself is intended to prepare patients to respond as soon as they identify a problem.

These elements of patient education are utilized in many studies involving a variety of diseases processes, including but not limited to COPD (Davis et al., 2015), Heart Failure (Vegesna et la., 2017, Bashi et al., 2017 and Varma et al., 2015), Chronic Kidney disease (Ishani et al., 2016), cancer (Cox et al., 2017) and neurological disease (Block et al., 2016). The pre-discharge patient education session going over the technology and the disease process is a consistent theme in RPM initiatives. Among studies powered to detect such an outcome, patients receiving RPM or telehealth interventions often report higher satisfaction and quality of life scores (Bashi et al., 2017 and Davis et al., 2015). This is found even in certain studies that fail to see improvement in their more clinical primary outcomes (such as 30-180 day re-hospitalization in one example (Davis et al., 2015)). RPM is an effective method for supporting family caregivers by improving their knowledge of the disease process and providing them a method for greater engagement in their loved ones' care. Here, combining telehealth with remote monitoring yields greater results, as RPM provides the opportunity for greater engagement while telehealth augments the longitudinal education component (Chi and Demiris, 2015). Education can be delivered to caregivers through telephone, web-based, or video platforms (Chi and Demiris, 2015 and Smith et al., 2012). Other services offered through this channel include problem-solving training, clinical consultation (Demiris et al., 2011), psychosocial or cognitive behavioral therapy (Demiris et al., 2011) and interactive RPM platforms through which patients and caregivers can monitor their own data. In a systematic review of telehealth tools to support family caregivers, Chi and Demiris, 2015 reported on the impact of these RPM and telehealth interventions upon the family and other caregivers. The components of well-being were defined as psychological health, quality of life, caregiving knowledge, coping skills, and other related factors. Chi et al., (Chi and Demiris, 2015?) reported that 95% of the studies looking for such outcomes reported significant improvements in the caregivers' well-being and that caregivers were satisfied and comfortable with telehealth[28].

3.1.3 Chronic disease management

Chronic conditions account for seven of the top ten causes of death and for 86% of the USA's $2.6 Trillion in annual healthcare expenditure (CDC, 2017). As discussed earlier, spatial accessibility is a key social determinant of healthcare outcomes for patients, particularly those requiring long-term follow-up and monitoring for acute decompensations. Among these patients, those with cardiac, pulmonary, neurological, and mobility problems are among the best studied. For patients with arrhythmia and heart failure, Cardiac Implantable Electronic Devices (CIEDs) have shown improved clinical outcomes with remote monitoring platforms (Varma and Pietro, 2015, Varma et al., 2015 and Piccini et al., 2016). In a historical cohort study by Varma et al., 2015, RPM use was associated with improved all-cause mortality in patients using all types of RPM-enabled CIEDs. The study included Pacemakers (PMs), implantable cardioverter-defibrillators (ICDs), cardiac resynchronization therapy (CRT) with pacing capability (CRT-P), and CRT with defibrillation capability (CRT-D). The cohort also showed a graded relationship between survival and increasing RPM use, as compared between high, low, and no RM use patients.

A challenge identified by Varma et al., 2015 is that a higher Charlson Comorbidity score (measure for higher disease burden) is associated with lower rate of RPM-utilization. This is potentially the case for many patients who would otherwise benefit from this technology. Other negative predictors include living below the poverty line, lacking health insurance, short and long-term unemployment, lower median income, and living in an urban neighborhood. Conversely, landline phone or cell phone in the home and completion of at least 4 years of college positively predict RM use, while age and sex are not associated positively or negatively.

The low rate of RPM-use affects many such studies, in spite of class I recommendation (level of evidence A) to use RM in all CIED patients to improve patient outcomes. In a nationwide cohort by Piccini et al., 2016 healthcare costs and all-cause hospitalization events were compared between those using RM and those not using RM. While only 37% of their cohort (n= 92,566 patients; mean age 72 ± 13 years; 58,140 [63%] men) utilized RPM, users had Charlson Comorbidity Index values similar to those not using RPM. Those using RPM had reduced risk of all-cause hospitalization (Hazard ratio 0.82; 95% confidence interval 0.80-0.84; $P < .001$) during follow-up. Additionally, RPM was associated with a 30% reduction in hospital costs (RM Use: $8720 per patient-year; Non-RM: $12423 per patient-year). Per 100,000 patient-years, RPM use was associated with $370,270,000 lower hospital payments, 9810 fewer hospitalizations, and 119,000 fewer days in the hospital. The low usage rate of RPM in this study highlights a great opportunity for improving patient outcomes and reducing expenditure.

COPD is a leading cause of mortality and emergency department visits. Furthermore, patients discharged afterwards have a high readmission rate. With increasing COPD prevalence, focus is shifting towards encouraging home-based self-management and prevention of exacerbations to reduce admissions and costs. In a study by Segrelles-Calvo et al., 2014, patients on long-term home oxygen therapy and severe COPD were enrolled in a cluster randomized controlled trial comparing ER visits, hospitalizations, length of stay, and need for non-invasive mechanical ventilations. After 7 months of monitoring and follow up, patients under the RPM intervention (home transmission of daily vital signs followed up by a monitoring center) did far better in all measures than patients receiving standard treatment (all $p<0.05$). Additionally, patients reported high satisfaction with the program.

Chronic management of Type 2 Diabetes Mellitus involves daily monitoring of blood glucose and periodic monitoring of hemoglobin A1c (along with ophthalmologic and podiatric specialist visits as required). Remote monitoring initiatives use RPM to assist with medication and blood glucose monitoring adherence and provide remote feedback on high blood glucose levels. The primary outcomes in these studies are often degree of adherence and clinical indicators of successful diabetes management, like hemoglobin A1c. Approximately 37% of patients on glucose-lowering oral medication stop using them within one year. Since medication non-adherence correlates with worse clinical outcomes, this is an important target for RPM interventions. In a systematic review comparing studies from 1990 to 2014, Farmer et al reported moderate improvement in medication adherence but minimal effect on clinical outcomes (Block et al., 2016). In a review which sought "to identify and classify barriers to adoption of remote health for management of type 2 diabetes," the authors concluded that technological barriers were the most responsible for limiting patient engagement (Alvarado et al., 2017). Among the studies reported on by this review, 48% reported challenges with scalability and technology illiteracy. Scalability was a more significant challenge in mid-income populations, while technology illiteracy was reported to disproportionately affect low-income populations.

The impact of these barriers is visible in the high dropout rates affecting many of these studies, with some reporting dropout rates as high as 57% (Alvarado et al., 2017). However, there are some instances where RPM use positively impacts clinical outcomes. In a recent report by Wang et al, an integrated approach combining remote monitoring of blood glucose, medication adherence, daily activity, and exercise was tested against conventional treatment in 212 patients followed up for six months (Wang et al., 2017). At 6-month follow up, fasting plasma glucose and triglyceride, 2-hour postprandial glucose, and HbA1c levels were all significantly lower in the RPM group versus the controls. Furthermore, more than 80% of the patients in the intervention adhered to using the RPM platform 2-3 days per week. However, the study did not include any patients who exhibited non-adherence within three months prior to screening (Wang et al., 2017). While the results of the study are encouraging, the exclusion criteria are extremely stringent and may have introduced selection bias by excluding subjects that would've had trouble consistently utilizing the RPM platform.

4. Challenges and Future Recommendations

RPM technology, despite its many advantages, often faces the larger challenges arising from signal quality, connectivity, data processing, and user reception (Baig et al., 2017, Davis et al., 2015, Block et al., 2016) and Bujnowska-Fedak and Grata-Borkowska, 2015). These are all determinants of the ultimate success or failure of any remote monitoring initiative. Emerging work addressing these challenges provides cues to the ways RPM may bridge gaps in patient-care.

With regards to signal quality, there are myriad ways that extraction of meaningful data can become difficult. Wearable sensors suffer from motion artifacts and wandering caused by body movements and respiration (Baig et al., 2017).

Ubiquity of wireless technology and, in many areas, exposed power lines can produce electromagnetic interference and confound collected results. Certain signals are especially affected by imperfect contact with the wearer's skin. ECG sensors must evolve to address this problem while also becoming more resistant to drying-out and therefore non-functional (Kaappa et al., 2017). Proposed solutions often promote on-site or cloud-based noise filtering before transmitting data to the central storage, but these solutions are still a work in progress.

Another challenge arises from connectivity (Gheorghiu and Ratchford, 2015). Patients in remote areas face several barriers to spatial accessibility. People in remote areas would benefit a lot from RPM and telemedicine implementation. The issue here is that remoteness itself is also a barrier to connectivity. Many RPM platforms rely on 3G/4G networks while others depend on wireless internet for transmitting information gathered by sensors to local storage and then to central repositories (Baig et al., 2017). In less economically developed areas, connectivity issues are sometimes coupled with limited access to electricity and consequently limited power supply. This sorely limits the RPM solutions available to patients in remote areas with little medical infrastructure.

Processing data from large scale RPM initiatives is enormously challenging. It requires capacity building drives at healthcare access points to train the staff in the usage, maintenance, and troubleshooting of these platforms. Additionally, new data processing software must be validated by testing them against large data sets from sample populations that reflect the demographic and medical profile of the target population. As dataset become larger and more complex, data processing software must become faster, consume less power, offer readier usability for new adoptees, and accomplish all this while minimizing cost. Innovations in cloud-based data processing and utilization of "big-data" concepts allow for machine-learning driven automation of routine healthcare administration. This includes early warning systems for adverse drug interactions/reactions, reminders for routine screening and testing, personalized therapeutics and dosing, and periodically automated calculations for risk to illnesses that are preventable by lifestyle modifications /pharmaceutical interventions.

5. Conclusion

RPM has demonstrably improved spatial accessibility to healthcare, based on several studies and reviews (Giger et al., 2015, Davis et al., 2015, Varma et al., 2015 and Piccini et al., 2016). Socioeconomic status, remoteness, and inadequate transportation access all inform spatial accessibility. These factors affect chronic disease severity and the ability to access and pay for healthcare services, among other determinants of adequate care. Ongoing work shows the potential for telehealth and RPM as tools for mitigating these access barriers. Spatial accessibility affects urban and rural populations, and policy-makers would benefit from utilizing GIS technology to guide resource allocation and predict future need. Telehealth and RPM initiatives have the potential to circumvent spatial access barriers and provide medical care to patients who are remote and would otherwise be inadequately covered. Negative predictors of adoption are related to living below the poverty line, lacking health insurance, being unemployed, not being in the work force, lower median income, and living in an urban neighborhood (Piccini et al., 2016). Future work must address solutions for improving ease of use among participants with these limitations. Furthermore, RPM and telehealth have potential for large-scale implementation but this will require robust solutions to signal quality, connectivity, data processing, and user reception issues.

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