ORIGINAL ARTICLE

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Conceptualization of Remote Patient Monitoring Program for Patients with Complex Medical Illness on Hospital Dismissal

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Abstract

Objective: To describe the creation of a scalable framework for a Remote Patient Monitoring (RPM) program tied to a large medical practice.

Patients and Methods: In July 2020, at Mayo Clinic Rochester, we initiated the process to combine human-centered design, health systems engineering, and clinical expertise to develop and refine RPM programs and explore new medical conditions where RPM could be beneficial. We report on the creation of the overarching RPM program, the development of a hybrid nursing model, the technology used for each population, and the lessons learned throughout the process.

Results: Four pilot programs for hospitalized patients with cirrhosis, acute kidney injury (AKI), post-pancreatectomy, and post-gastroenterology (GI) procedures were launched. The 4 programs enrolled a range from 0 patients (post-GI procedures) to 91 patients over 5 months (AKI) for RPM programs ranging from 30 days to 96.5 days in average duration. Three of the programs continue enrollment (cirrhosis, AKI, and post-pancreatectomy), and one program was discontinued.

Conclusion: RPM can uniquely facilitate the transition from hospital to home, decrease hospital length of stay, and optimize hospital capacity and staffing resources in select scenarios. To achieve positive results at the health care system level, RPM interventions require a change in the model of care. However, not all care models or medical conditions lend themselves to RPM, which should be explored in pilot testing.

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Serious and complex medical illness has been associated with reduced quality of life, increased morbidity and mortality, and high medical and personal costs.[1] Although society attempts to control the rising costs of health care across the globe,[2] important need exists for acute care hospital beds[2,3] as the population ages and becomes increasingly medically complex.[4] Strains in acute care hospital capacity have been linked to decreases in care, efficiency and quality,[5] delays in necessary elective and emergency treatment,[3] decreased patient and hospital employee satisfaction,[5] and increased costs for health care systems and patients.[6] As the health care industry drives toward patient centered care and comfort, one proposed solution is extending the reach of hospital care models into the post-discharge period through digital health tools like remote patient monitoring (RPM).

Remote patient monitoring is a subset of telehealth that uses digital applications and

devices to collect, analyze, and record physiologic and other patient-generated health data outside of a clinical setting.[7] Telemonitoring has been used for patient care since the 1990s, but more recent technological advances have enabled receiving information from patients through intelligent, continuous sensors, wearable and handheld devices, implanted medical devices and cameras, smartphones, tablets, video and audio technologies, and digital photography. The RPM offers the opportunity to detect decompensation of chronic conditions and prevent hospitalization.[8] The other advantages of RPM are the ability to continuously monitor patients, monitor patients with mobility issues, obtain data while patients continue daily activities and intervene in a real-time manner. The RPM can also facilitate care delivery to remote and rural areas with reduced access to health care,[7,9] shown to reduce mortality and hospitalization in select conditions,[10,11] and found the ability to care for patients with for diabetes,[11] heart failure,[10] and chronic obstructive pulmonary disease.[12] From the patients' perspective, remote monitoring can be used to improve patient self-management of condition(s), promote health and wellbeing, and facilitate patient interactions with health care providers (s).[13,14]

As our knowledge of how RPM services can support patient care continues to grow, uncertainty remains about how best to match and seamlessly connect patient need with available technologies resources. We undertook an interdisciplinary initiative in 2020, combining principles of human-centered design, health systems engineering, and clinical expertise to draft a new framework for clinical care leveraging RPM. This innovative program uses RPM, tailored care plans, and virtual and specialized nursing interventions to achieve specific objectives. Our primary aim was to facilitate earlier hospital discharges across the RPM program at large and to facilitate the following objectives specific to individual pilots: avoid post-procedural hospitalizations, reduce hospital length of stays, prevent emergency department visits, and avoid hospital readmissions. The primary objective of this paper was to delineate the creation of a scalable framework for RPM programs integrated into a large medical practice. In addition, we aim to describe the iterative development of cases within this framework while also providing insights into the future trajectory of RPM programs for patients with complex medical conditions.

METHODS

Patient Journey Map, Design Themes, and Program Service Vision

The planning for RPM programs started in July 2020, with the first program launch in April 2021. Human-centered design was used to understand needs for RPM. This approach begins with understanding the needs of the user, in this case the needs of patients and members of care teams, who will be affected by the new product, service, or experience. The approach was on the basis of the creation and development of clinical programs reported in previous studies[15] and initially focused on 2 patient populations: a chronic, complex medical condition (cirrhosis) and a complex surgical intervention resulting in substantial lifestyle modification (pancreatectomy). Through the human-centered design process, we worked to deliver 4 products: patient journey maps to describe the overall experience of patients undergoing hospital dismissal for 1 of our 2 use cases[16]; design themes that would be used to create the ideal RPM solutions for both patients and providers (Table 1); an overall service vision to outline components necessary to deliver this new model of care to patients[16]; and program scalability matrix that describes the clinical personas of patients to be served by the new program (Figure).

To achieve these deliverables, we conducted interviews with patient groups to understand their medical journeys, care challenges, experiences, and the different behaviors and emotions they experienced. To ensure patient safety and integration of proposed care models with current care processes, we conducted detailed interviews with clinical care teams. The journey mapping, theme development, service vision, and scalability matrix represented the discovery phase of this work. These frameworks were used to develop initial program vision and offerings.

Characteristics of Clinical RPM Models

As heterogeneity exists between clinical practice areas, present and future state workflow

TABLE 1. The New Remote Patient Monitoring Programs Design Principles That Describe the Ideal of Solution On the Basis of Patient Reported Values

Responsive	Solutions that identify and pro-actively respond to changing patient needs and provide supportive communication.
Intelligent	Smart solutions to help identify appropriate patients, provide evidence-based care plans, and monitoring.
Seamless	Solutions that do not place burden on patients and provide a seamless integrated experience.
Collaborative	Solutions that are collaborative between providers and patients and integrated between different departments.
Personalized	Solutions that consider the medical, psycho-social, and behavioral needs of patients.

analysis was used to understand how RPM technologies could best fit into each clinical practice area. The derivation of clinical goals of care was initiated with each clinical practice area, facilitated by digital implementation coordinators within Mayo Clinic Center for Digital Health. Clinical goals were aligned with technical capabilities either already within Mayo Clinic portfolio of technology tools, or external assessments were performed to incorporate new tools needed to meet the needs of patients and care teams. Once goals of care were outlined and technological capabilities were incorporated into Mayo Clinic digital ecosystem, patient eligibility criteria were outlined and the details of the program build were defined (eg, vitals, symptom assessment questions, and escalation pathways). To aid in program administration and oversight, a small set of standardized measures were tracked, and include total program enrollment (n), length of stay of index hospitalization where patient was enrolled in RPM program (median, days), and RPM program duration (median, days).

Discharge processes to support the introduction of patients to the RPM technologies and to walk patients through their RPM journey was initiated by our digital care specialists. Standardized videos have been created by Mayo Clinic Center for Digital Health to provide an overview of the RPM program and to help patients use the RPM tools. From a care team perspective, decision trees and workflows were created to help identify patients who may be eligible for program enrollment. Program summaries outline detailed insights into each RPM program. Contact information for clinical nursing, virtual nursing, and physical program leads are always available on intranet servers to care team members. Communications to support clinical care teams within hospital practices responsible for discharging patients, outpatient specialty care teams who interact with patients on hospital dismissal, and primary care providers responsible for holistic care of patients were done within our electronic medical record. Managing providers affiliated with the care of patients enrolled within an RPM program receive secure messages to alert them to escalations and graduation from each RPM program.

Development of the RPM Hybrid Nursing Model

To support new programs, the team identified the need to expand nurse coverage to 7 days per week with day and evening hours coverage and an emergency overnight call line. A workgroup was formed to propose a scalable model that could be applied broadly across the practice. Nursing leadership asked the team to consider innovative options that blur lines between traditional ambulatory and inpatient nursing roles to provide seamless RPM support and position the practice for future models of care. The workgroup considered staffing models, patient clinical need, necessary nursing skills and clinical expertise for remote monitoring (specialty vs generalized), wage and hour laws, regulatory adherence, financial effect, staff satisfaction, and patient experience. The workgroup evaluated models where the RPM nursing support was provided entirely by telemedicine nurses and where monitoring was provided entirely by nurses in the specialty practice who have expertise on a particular patient population. The workgroup identified substantial advantages and disadvantages to the specialty practice model, mostly from a cost and resource perspective. The workgroup also looked at hybrid model combining the best aspects of the telemedicine nurse and specialty nurse models (Table 2). The workgroup determined that the best model for the new RPM programs was a hybrid model providing optimal resource utilization and ensuring patients had access to specialty care when their clinical condition

TABLE 2. Nursing Models for Remote Patient Monitoring.

Telemedicine Registered Nurse model
• Specialized in telemedicine and general nursing • Familiar with technology roles and workflows • Use existing workflows within the RPM nursing teams
Specialty Registered Nurse model
• 100% care by specialty nurses familiar with disease process • Nurses may know patients already from previous specialty outpatient care • Close collaboration with inpatient care team
Hybrid RN model (telemedicine nurse monitors with escalation to specialty nurse when warranted)
• Combine both specialties of telemedicine nursing and speciality practice (eg, gastroenterology) nursing • 24/7 model of care • Close collaboration with inpatient care team

warranted escalation. Additional insight into the virtual nursing model can be seen elsewhere.[17]

RPM Program Technology

Our RPM program technology involves a collaboration with a specific vendor. This vendor facilitates the shipment of a comprehensive equipment kit to patients through a logistics partner. The composition of this kit varies on the basis of the patient's enrolled plan; however, a standard kit comprises a blood pressure cuff, pulse oximeter, scale, and thermometer. These devices are interconnected by Bluetooth technology, with an accompanying tablet included in the kit. Patients use this tablet to complete daily symptom assessments, record vital measurements, and engage in text-based communication with our dedicated RPM registered nurse (RN) team. The data collected is efficiently managed through the vendor's dedicated dashboard, allowing our RPM RN team to closely monitor patients' progress. Furthermore, data integration into the larger health care framework, including our electronic medical record, enables seamless collaboration and information sharing among the care team, with nurses being able to leave essential notes for the team's reference.

RESULTS

Program Development and Patient Enrollment

Cirrhosis Program. The Gastroenterology and Hepatology division within the Department of Medicine underwent a discovery period to identify patient population and technological requirements to aid in the goals of RPM. Patients with liver cirrhosis experience high rates of infection, ascites, and variceal bleeding and have estimated 25%-37% readmission rate to the hospital within 30 days of discharge.[18,19] Patients with cirrhosis are in a higher acuity, longer duration quadrant of patient population (Figure). On the basis of this high degree of clinical need, cirrhosis patients were identified as a group that could benefit from development of an RPM program. The pilot patients were cirrhosis patients hospitalized at the primary hospital campus of Mayo Clinic in Rochester, MN. Patients were referred to the program if they had a diagnosis of decompensated cirrhosis and were under the care of a Mayo Clinic hepatologist (Table 3). Enrolled patients were educated on RPM equipment at hospital dismissal. Patient vitals were monitored daily by RPM nurses 7 days per week for at least 90 days, and longer depending on patient need. The RPM nurse contacted the patient by phone for an initial welcome and assessment, and every 2 weeks until a closing call at final graduation. Symptom assessment calls were conducted for any red flags or escalations generated by the monitoring algorithm on information collected through the monitoring equipment.

The cirrhosis program enrolled 89 patients over 20 months of the program. The median length of stay was 3.0 days, with a median RPM program duration of 96.5 days. The cirrhosis pilot was the first program to trial

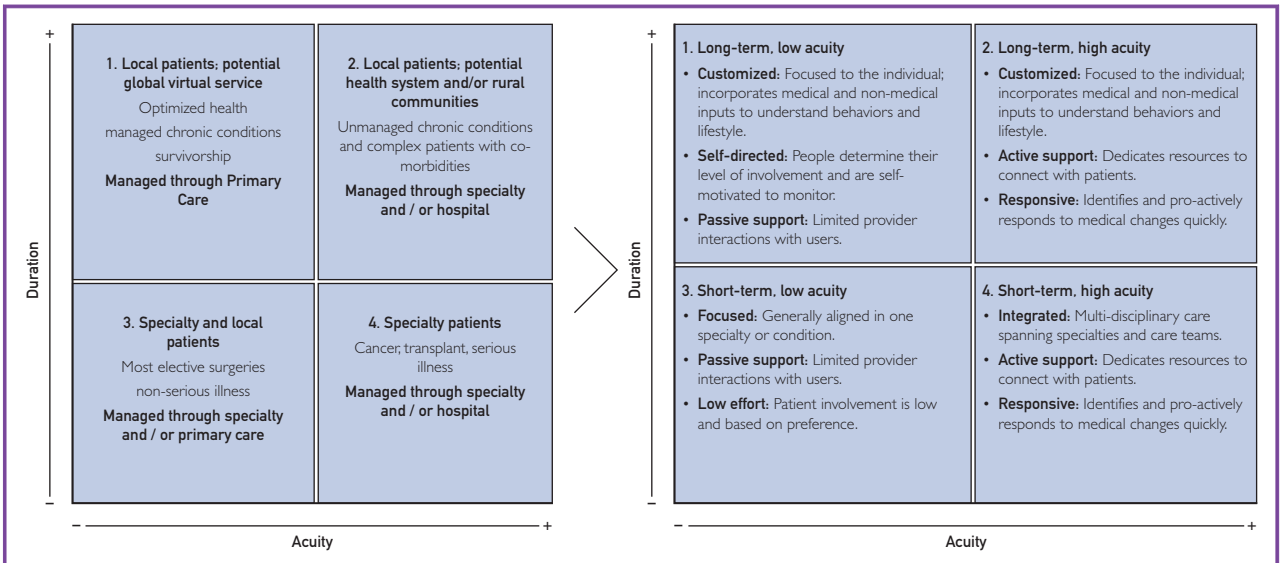

FIGURE. Program scalability framework on the basis of considering the duration of monitoring vs patient acuity. Cases within each quadrant were identified for initial development to create workflows and partnerships to enable program scaling to new patient groups and practice areas.

the new RN staffing model, paving the way for an innovative approach to nurses and ambulatory nurses to meet the needs of the patients.

Post-Gastrointestinal Procedures Program. To investigate the role of RPM within a population that was considered lower acuity and for a shorter duration (Figure), our team partnered with the gastroenterology procedural team, who oversee the care of patients in our short-stay inpatient procedural unit. Most patients undergoing a GI procedure are discharged safely. However, some patients continue to experience pain related to their procedure or suffer post-procedural nausea, which requires intravenous administration of medication. These select individuals remain hospitalized for typically less than 24 hours before discharging to home. Proceduralists hypothesized that leveraging RPM technology would afford patients and caregivers a more comfortable night of healing at a hospital-adjacent hotel. Remote monitoring was planned to occur for 23 hours after discharge from the hospital, through a hybrid nursing model with clear escalation pathways (Table 3).

The focus for the monitoring was patient recovery, pain control, nausea management, and monitoring for bleeding. The new RPM program team engaged with Mayo Clinic legal team to solidify the regulatory and legal requirements of partnering with an external hotel. The team worked closely with several clinical teams, including partnering with community paramedics and emergency department telehealth teams to ensure safe care for patients. On open enrollment in the program, patients were given the opportunity to stay overnight in the hospital, or transfer to the program hotel. All patients and caregivers felt more comfortable remaining within the hospital, and the pilot was concluded prior to enrollment. Lessons learned around staffing workflows from the preparation for the pilot were applied to future transitional care spaces at Mayo Clinic. The RPM team continues to partner with practice areas to explore the role of RPM for low acuity, short-term medical needs.

Acute Kidney Injury Program. The next program to pilot RPM solutions for high acuity, longer duration patients (right upper quadrant, Figure) was for acute kidney injury (AKI) survivors. At least 30% of patients with AKI survivors lack appropriate follow-up after

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TABLE 3. Details of Initial Pilot Programs for Hospital Dismissal RPM Program

	Cirrhosis	Post-Gastrointestinal Procedures	Acute Kidney Injury	Postpancreatectomy
Go-live date	April 13, 2021	August 23, 2021	October 18, 2021	October 22, 2022
Maximum program duration	90 d	24 h	90 d	30 d
Patient population	Hospitalization within previous 4 wk for cirrhosis (decompensated cirrhosis, such as ascites, hepatic encephalopathy, or previous variceal GI bleeding) with a longitudinal hepatologist identified	Patients undergoing endoscopic submucosal dissection, peroral endoscopic myotomy, transoral incisionless fundoplication, or endoscopic sleeve gastroplasty, and have been discharged from anesthesia care protocols	Hospitalized patients with acute kidney injury stage 2/3 and had nephrology consult during hospitalization	Hospitalized hepato-pancreatectomy-biliary patients who are clinically stable and at low risk for adverse events per infectious disease guidelines
Vitals/labs monitored	Blood pressure Heart rate Weight Pulse oximetry Oral temperature	Blood pressure Heart rate SpO2 Skin temperature	Blood pressure Heart rate Weight SpO2 (as needed) Electrolyte Serum creatinine Urinalysis	Blood Pressure Heart rate Weight Oral temperature SpO2 Blood Glucose
Frequency of monitoring	Daily	Hourly for first 4 hours, then every 4 hours through 24 hours	Daily vitals and weekly labs	Daily, glucose 4 × daily
Graduation criteria	Vital signs within range for 1-2 wk, and patient verbalizes knowledge of self-management of medication(s), symptom recognition, and healthy coping	Vitals stable for 24 hours	Stable serum creatinine levels for 2 wk	Vitals and symptoms stable and completed follow-up, in person visit
Number of patients enrolled	89 in 20 m	N/A	20 patients in 5 m	91 patients in 5 m
Index hospital length of stay (median)	3.0 d	N/A	7.0 d	6.0 d
RPM program duration (median)	96.5 d	N/A	30.0 d	34.0 d

RPM, Remote Patient Monitoring.

hospital discharge.[20,21] A highly dynamic posthospital course requires close monitoring for electrolyte imbalances, worsening of kidney function, volume overload or depletion, and other signs or symptoms that warrant hospital readmission. We implemented the RPM program for individuals who experienced stage 2 of the 3 AKI and underwent nephrology consultation while hospitalized (Table 3).[22] On enrollment in the AKI RPM program, AKI education was provided, and home monitoring technology was distributed. Patients self-monitored vital signs, weight, and symptoms daily. Weekly serum creatinine and electrolyte evaluations were scheduled. Nephrology nurses evaluated the data daily and adhered to prespecified protocols for management and escalation of care as needed. The maximum program duration was 90 days. The AKI RPM participants were eligible for graduation if they remained off dialysis, had a stable serum creatinine level for 2 consecutive weeks, and had no urgent or emergent results in the preceding 1-week interval. Twenty patients were enrolled in AKI RPM in the first 5 months. The median length of stay was 7.0 days, and the median RPM program duration was 30.0 days.

Post-pancreatectomy Program. Pancreatectomy is a complex procedure requiring necessary lifestyle changes for patients to manage diabetes[23,24] and augment digestive enzymes.[25] Depending on the type and complexity of the pancreatectomy procedure, patient healing and adjustment time can last several months.[25,26] The average hospital stay related to the pancreatectomy is 11-13 days[27] and up to 35% of patients experience a readmission within 30-days,[27] requiring patients and caregivers to remain geographically near to the limited number of surgical practices available to perform these complex operations. The ability to extend care outside of the hospital to these patients and caregivers enabled our program to explore this high acuity patient population with shorter duration of required monitoring (Figure). Before the development of this program, most RPM programs focused on vitals monitoring. With this patient population, the need for continuous blood glucose monitoring was paramount. In addition, post-surgical recovery symptoms also including weight loss, nausea and vomiting, and diarrhea needed monitoring as potential signals of a post-operative complication. The clinical outpatient team met with the RPM team and surgical teams to prepare the workflow and transitions of care. Vitals were monitored daily 7 days per week. Blood glucose was monitored 4 times per day (Table 3). The initial week of the program was monitored by the diabetes nurse educators and then transferred to RPM nurses for the remaining weeks of the 4-week program. Patients received an initial assessment by a phone call, and weekly calls and symptom calls if red flags were observed during monitoring. Patients graduated from the program after 4 weeks, or at their 1-month operation follow-up appointment if doing well. Length of RPM enrollment could be extended if additional monitoring was needed. The post-pancreatectomy RPM program has enrolled 91 unique patients in 5 months. Among the first 50 graduates the median length of stay was 6.0 days, and the medical RPM program duration was 34.0 days.

DISCUSSION

We have outlined the vision and execution of a new RPM program to extend care to patients discharging from a hospital stay. The primary intent was to promote patient-centric models in which patients continue to be linked to clinical teams to advance their care and avoid hospital readmission. Our developmental process to create a service vision for the new RPM programs involved envisioning and enabling the skills of nursing teams to support patients with complex medical diseases. We experienced success with models of care engaging patients with cirrhosis, AKI, and following a pancreatectomy that shared features of being high acuity with moderate to long courses of illness.

Throughout the process, the team learned several valuable lessons around workflows, transitions of care, and technology. First, we learned that providing a personalized approach was an important factor in determining the success of an RPM intervention. Second, we learned that patient adoption increased considerably when the enrollment discussion occurred in person as a part of

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the discharge planning discussion and when remote monitoring was posed as a standard of care and not as an optional program. Third, we learned the importance of developing connectivity between telemedicine and specialty practice nurses for a seamless experience for the patient and ease of escalating care when needed. Fourth, we learned that health care transformations can occur when medicine rises to meet public health crises. Historically, reimbursement from both public and private payers was a limiting step for many health care providers interested in serving patients with RPM solutions.[28] However, the COVID-19 pandemic prompted a Medicare-supported expansion of telehealth services, augmenting the already available forms of virtual care for patients. This public health emergency facilitated the establishment of a new billing system that allowed to bill the services provided by RPM. Finally, increased availability of technology and access to the internet throughout the country can play an important role in facilitation of RPM program implementation. It is estimated that nowadays within the United States nearly 93% of Americans use the internet, 97% own a cellphone of some kind, of which 85% are smartphones enabled by internet technology, 75% own a desktop or laptop computer, and 50% own a tablet computer.[29] Expanding digital and technical capabilities offered easier access and allowed comprehensive monitoring and interventions of RPM patients.

The design and execution of our RPM program offer a replicable framework for health care institutions aiming to extend postdischarge care. By leveraging principles of human-centered design, health systems engineering, and clinical proficiency, our program establishes a scalable foundation that can be adapted to diverse patient populations and medical contexts. Patient recruitment volumes indicate a positive response to our approach and underscores the program's appeal and suggests a strong potential for effective patient outreach and enrollment. The outcomes observed in our RPM program reflect positively on patient care and health care efficiency. Achieving possible earlier patient discharges, mitigating post-procedural hospitalizations, and shortening overall hospital stays indicate possible favorable effects on length of stay. These trends align with the goals of reducing hospitalization durations and readmission occurrences, implying promising outcomes. The nursing structure, described in detail, plays a pivotal role in the success of our program. The integration of virtual and specialty nursing resources, coupled with the utilization of remote monitoring, contributes to positive patient outcomes, and reduced hospital readmissions. Given the tangible benefits observed in patient care, health care efficiency, and readmission reduction, the investment in this nursing structure is justified and stands as a worthwhile endeavor for achieving improved health care outcomes.

During the COVID-19 pandemic, Mayo Clinic was able to create and scale the RPM program, serving more than 7000 patients with RPM across 41 US states.[30] Patients with COVID-19 at risk for severe disease who enrolled and engaged in the RPM program experienced significantly lower 30-day, all-cause hospital utilization, total cost of care, and mortality.[31] The work completed by the COVID-19 RPM program reports the ability to manage large numbers of patients for acute episodes of care, and the ability to care for patients with for diabetes,[11] heart failure,[10] chronic obstructive pulmonary disease[12] through RPM have been reported. Remote-monitoring for post-procedural and postsurgical patients is less well reported on,[32] but we believe that frameworks for extending care to these new populations can be developed.

RPM holds promise for transforming the health care but requires further development and optimization. The RPM could be more successful if it could more accurately anticipate disease exacerbations and decompensations to facilitate a timely and personalized response.[5] Artificial intelligence holds promise for the identification of patient populations most likely to benefit from RPM.[33] It can also enable detection of aberrations in continuous monitoring data to facilitate the early detection of disease exacerbations or health decline. Although existing validated algorithms have shown to be reliable for predicting and detecting chronic disease-related events, they have not been tested in experimental studies for RPM programs. If the field of RPM is to progress, future studies should

address this gap in knowledge by using high performance validated algorithms in clinical trials.[13] The RPM can facilitate empowerment of patients and caregivers to play a more active role in patient care.[8] There has been adoption of RPM monitoring programs for distinct populations but in the future, it will need large and widespread implementation in other areas.

CONCLUSION

The RPM offers a unique opportunity to bridge the care transition from hospital to home, decrease hospital length of stay, and optimize hospital capacity and staffing resources. To achieve positive results at the health care system level, RPM interventions require a change of the model of care. However, not all care models or diseases lend themselves to RPM and pilot testing is important to learn this. Team-based interprofessional, multidisciplinary collaboration and connectivity between nurse teams is critical for the success of RPM programs.

POTENTIAL COMPETING INTERESTS

Study authors report no conflicts of interest with this work.

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Abbreviations and Acronyms: **AKI**, acute kidney injury; **GI**, gastrointestinal; **RPM**, remote patient monitoring

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