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# Remote Treatment Monitoring on Hospitalization and Technique Failure Rates in Peritoneal Dialysis Patients

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**Abstract**

*Background*

An integrated kidney disease healthcare company implemented a peritoneal dialysis (PD) remote treatment monitoring (RTM) application in 2016. We assessed if RTM utilization associates with hospitalization and technique failure rates.

*Methods*

We used data from adult PD patients (age ≥18 years) treated from Oct 2016 through May 2019 who registered online for the RTM. Patients were classified by RTM use during a 30-day baseline after registration. Groups were: non-users (never entered data), moderate users (entered 1-to-15 treatments), and frequent users (entered >15 treatments). We compared hospital admission/day and sustained technique failure (required >6 consecutive weeks of hemodialysis) rates over 3, 6, 9, and 12 months of follow-up using Poisson and Cox models adjusted for patient/clinical characteristics.

*Results*

Among 6,343 patients, 64.5% were non-users, 10.6% were moderate-users, and 24.9% were frequent-users. Incidence rate of hospital admission was 22% (incidence rate ratio (IRR)=0.775; p=0.002), 24% (IRR=0.762; p<0.001), 23% (IRR=0.768; p=<0.001), and 26% (IRR=0.737; p=<0.001) lower in frequent-users after 3, 6, 9, and 12 months respectively versus non-users. Incidence rate of hospital days was 38% (IRR=0.618; p=0.013), 35% (IRR=0.654; p=0.001), 34% (IRR= 0.657; p=<0.001), and 32% (IRR=0.680; p<0.001) lower in frequent-users after 3, 6, 9, and 12 months versus non-users. Sustained technique failure risk at 3, 6, 9, and 12 months was 33% (hazard ratio (HR)=0.671; p=0.020), 31% (HR=0.686; p=0.003), 31% (HR=0.687; p=0.001), and 27% (HR=0.726; p=0.001) lower in frequent-users versus non-users. Among a sup-group of survivors of the 12-month follow-up, sustained technique failure risk was 26% (HR=0.736; p=0.023) and 21% (HR=0.793; p=0.054) lower after 9 and 12 months in frequent-users versus non-users.

*Conclusions*

Our findings suggest frequent use of a RTM application associates with less hospital admissions, shorter hospital length of stay, and lower technique failure rates. Adoption of RTM applications may have the potential to improve timely identification/intervention of complications.

**Key Words**

Remote Monitoring; Peritoneal Dialysis; Hospitalization; Technique Failure; End Stage Kidney Disease; Chronic Kidney Disease

## Introduction

The modality of peritoneal dialysis (PD) is suggested to associate with favorable outcomes compared to in-center hemodialysis (HD), however, technique failure is common and adjusted rates for the hospital length of stay tends to be longer in PD (1-3). In the United States, home dialysis patients typically have monthly clinic visits where their clinical status, assessment of treatment quality and adherence is assessed based on written treatment records and self-reported complications (4, 5). This monitoring process poses limits to the clinicians view of complications and clinical needs, which can impede timely medical decisions.

Remote monitoring systems may improve the care teams ability to actively identify urgent concerns in PD patients and react in a timely manner with diagnostic examinations, interventions, or patient education (6). Remote monitoring systems broadly include an array of technologies and processes in the areas of telemedicine/telehealth such as telephonic/video assessments, connected health sensors, and health record portals (6). Prior reports of various types of remote monitoring systems tested in the PD population suggest they associate with improvements in patient satisfaction, quality of life, nutrition, exit site infection rates, peritonitis rates, and hospitalization rates (7-13). However, patient groups included in the evaluations of remote monitoring systems to date are small and the findings may not be generalizable.

A large integrated kidney disease healthcare company started using a remote treatment monitoring (RTM) application throughout its dialysis organization in the United States since October 2016. The provider constructed and integrated the RTM system into its clinical systems as a quality improvement process. The RTM is an online portal-based treatment record application, whereby patients can create an online account and record the details of individual PD treatments, associated vital signs, and complications. We aimed to assess the associations between the level of utilization of the RTM application and hospitalization and technique failure rates.

## Materials and Methods

### *General Design*

We performed a retrospective analysis to assess the longitudinal associations between the frequency of use of the RTM in PD patients and outcomes after deployment in a dialysis organization in the United States. This analysis was performed under a protocol that was reviewed by New England Independent Review Board who determined it was an exempt assessment of existing patient data from a quality improvement process, which was anonymized and did not require informed consent per title 45 of the United States Code of Federal Regulations part 46.102 (Needham Heights, MA, United States; NEIRB# 1-9652-1). The analysis was conducted in adherence with the Declaration of Helsinki.

### *Patient Population*

We used data from adult PD patients (age ≥18 years) treated anytime during 01 Oct 2016 to 31 May 2019 at the dialysis organization (Fresenius Kidney Care, Waltham, MA, United States) of a large integrated kidney disease healthcare company (Fresenius Medical Care, Bad Homburg, Germany). We included data from all PD patients who: 1) registered online and created a RTM account on, or before 31 May 2018, 2) were treated continuously with PD for at least 30 days after registration, and 3) were not hospitalized within 30 days after registration. We excluded patients with: 1) a body mass index (BMI) >65 Kg/m$^2$, or 2) missing data for any covariates used for the adjustment of the analysis (refer to the variables section of the materials and methods).

### *RTM Application*

The RTM named the “PatientHub” is a health record portal technology available to all PD patient treated by the dialysis organization in the United States who have internet access. The RTM can be used through either a secure personal website portal, or mobile device application. After the creation of a personal RTM account and profile, patients can: 1) view their dialysis orders, laboratory results, concomitant medications, and supply orders, and 2) document their daily PD treatment data, vital signs, and complications. A schematic of the prior monitoring process and RTM process is shown in **Figure 1a and 1b**.

The daily PD treatment data documented in the RTM includes the treatment date, total ultrafiltration from cycler, dialysate type, bag size and number of bags used, medications added to the dialysate, as well as details on any manual exchanges performed. The daily clinical data documented includes weight, blood pressure, pulse, temperature, blood glucose, and confirmation of routine exit site care. The data on complications documented daily includes drain/fill, PD fluid, or exit site issues. Once submitted by the patient, the data is displayed in the electronic medical record (EMR) for the care team to review. The care team is instructed to review patient RTM entries on at least a daily basis on business days, but the timing of the daily review is at the discretion of the clinician. A preview of the PatientHub RTM application is shown in **Figure 2**.

*Variables*

The dependent variables were hospital admission counts per patient year (PPY), hospital days PPY, and sustained technique failure counts (PPY) from 30 days after RTM registration to 3, 6, 9, and 12 months of follow-up. Sustained technique failure was defined as PD complications that required patients to receive >6 consecutive weeks of treatment with HD.

The independent variables were the frequency of RTM use during the baseline period 30 days after online registration. We defined non-users as patients who never documented any treatment record in the RTM within 30 days of registration, moderate-users as patients who documented 1 to 15 treatment records in the RTM within 30 days of registration, and frequent-users as patients who documented more than 15 treatment records in the RTM within 30 days of registration. These cut points for classification of the frequency of baseline RTM use were chosen based on the distribution of data; most patients tended to use the RTM more than 15 times, or never within 30 days of registration.

Covariates used for the description of the baseline patient characteristics and for adjustment of statistical models included age, sex, race, ethnicity, dialysis vintage, alcohol use, urbanicity of residence, education level, congestive heart failure, diabetes, ischemic heart disease, albumin, residual kidney function (RKF), and weekly Kt/V. The most recent categorical variables to the date of registration were recorded. The mean value of continuous variables during 30 days from RTM registration was computed and recorded, with exception of RKF that was determined from the most recent value.

*Statistical Methods*

Adjusted Poisson regression models were constructed to assess the associations in hospital admission and day rates at the 3, 6, 9, and 12 months of follow-up periods for non-users (reference) versus moderate-users and frequent-users. The number of days patients were actively receiving dialysis during the follow-up period (patient exposure days) was used to calculate the hospital admission and day rates PPY.

An adjusted Cox regression model was constructed to assess the associations in sustained technique failure rates at the 3, 6, 9, and 12 months of follow-up periods for non-users versus moderate-users and frequent-users. A Kaplan Meier curve with log-rank tests was used to assess the associations in the time on PD modality over the 12 months follow-up for non-users versus moderate-users and frequent-users.

For hospitalization and technique failure rates, we censored data on patients who died, received a transplant, or where discharged from the providers clinic network at end of each respective 3-month period of the 12-month follow-up.

Similar to the previous analysis, adjusted Cox regression methods were used in a sub-analysis of survivors of the 12-month follow-up period to assess the associations in technique failure rates and the time on PD modality in a group of patients who had equivalent opportunities to experience a technique failure. This sub-analysis of survivors excluded all attrition (patients who died, received a transplant, or where discharged from the providers clinic network).

**Results**

*Patient Characteristics*

In a population of 36,577 PD patients treated at a large dialysis provider during the analysis period, 11,079 adult patients were treated by PD for 30 days without being hospitalized during baseline and completed the online registration creating a RTM profile. Among this cohort, we included data from 6,343 patients at 931 clinics, and excluded 4,736 patients due to only incomplete/missing data on covariates used in the adjustment of the analysis (**Figure 3; Table 1**). Among eligible patients (n=6,343), 64.5% never entered treatment data (non-users), 10.6% entered 1 to 15 treatment records (moderate-users), and 24.9% entered more than 15 treatment records (frequent-users) during a 30 day baseline period after registration. Patients mean age ranged from 54 to 58 years old between groups (**Table 2**). Frequent-users tended to more often be of a white race, non-Hispanic ethnicity, educated, and had a shorter dialysis vintage.

The within group trends of RTM usage were fairly sustained over the 12-month follow-up, as compared to baseline, yet frequent-users had decreases in the mean number of entries (**Figure 4**). On the 12$^{th}$ month of follow up, frequent-users on average documented 10 treatments in the RTM.

*Longitudinal Hospitalization Rates Associated with RTM Use*

Higher RTM usage in the 30 days following the start date was found to be associated with progressively lower unadjusted hospital admission and day rates in the follow up periods (**Figures 5a and Figure 5b**). A Poisson analysis showed the incidence rate of hospital admission was 22%, 24%, 23% and 26% lower in frequent-users of the RTM application after 3, 6, 9, and 12 months of follow-up, as compared to non-users (**Table 3**). The incidence rate of a greater hospital length of stay in days was found to be 38%, 35%, 34% and 32% lower in frequent-users of the RTM application after 3, 6, 9, and 12 months of follow-up versus non-users (**Table 4**). Albeit qualitative differences were observed favoring moderate-use of the RTM, there were not significant differences compared with non-users.

*Longitudinal Technique Failure Rates Associated with RTM Use*

We observed higher RTM usage in the 30 days following the start date was associated with lower rates of sustained PD technique failure (i.e. required >6 consecutive weeks of treatment with HD) in all follow up periods (**Figure 6**). A Cox analysis showed the adjusted risk of sustained PD technique failure at 3, 6, 9, and 12 months of follow-up was 33%, 31%, 31% and 27% lower in frequent-users of the RTM versus non-users (**Table 5**). Kaplan–Meier estimate for PD duration days without sustained PD technique failure identified frequent-users remained on PD longer compared to non-users (log-rank test frequent-users p=0.024; **Figure 7a**). No significant differences were found in sustained technique failure rates in moderate-users compared to non-users.

A Cox analysis of a subgroup patients who survived the entire 12 month follow-up period and continued to be treated in the providers clinics confirmed higher RTM usage was associated with 26% and 21% lower adjusted risk of sustained PD technique failure in frequent-users versus non-users at the 9 and 12 month follow up periods (**Table 6**). However, we did not find significant differences between moderate-users and non-users of the RTM. In this subgroup of survivors, we also observed the adjusted risk of sustained technique failure was 51% and 42% lower in moderate-users of the RTM at 3 and 6 months of follow-up compared to non-users, yet no significant differences were found at later timepoints. The Kaplan–Meier estimate of PD duration days without sustained PD technique failure showed that frequent-users of the RTM in the survivor subgroup remained on a PD modality longer than non-users (log-rank test frequent-users $p<0.001$; **Figure 7b**).

**Discussion**

In a large population of PD patients who registered online for the PatientHub RTM application, we found higher RTM use was associated with lower hospitalization and sustained technique failure rates. Hospital admission and day rates were observed to be 22% and 38% lower within 3 months, respectively, and continued to decrease in frequent-users of the RTM over the 12 months of follow-up compared to non-users. The risk of sustained PD technique failure (i.e. required >6 consecutive weeks of HD) was about 30% lower during follow-up for frequent-users versus non-users of the RTM. Assessment of a subgroup of survivors of the 12-month follow-up period found consistent trends, but significant differences were only observed at the 9- and 12-month follow-up periods in frequent-users versus non-users. Consistent trends were seen with respect to moderate-users of the RTM versus non-users, albeit outcomes did not significantly differ with exception of sustained PD technique failure rates in the subgroup of survivors at the 3- and 6-month follow-up periods. These results further substantiate prior findings suggesting use of other RTM systems in PD patients may reduce hospital rates (14, 15), and reveal frequent RTM use may also have the potential to increase sustained use of PD as a modality.

The associations between RTM use in PD patients and hard outcomes has been reported in a limited number of small cross-sectional analyses. A study of 63 patients who had a RTM system incorporated in their PD cycler found that the incidence of hospital admissions was 39% (IRR=0.61; 95% confidence interval (CI) 0.39 to 0.95) lower and hospital days was 54% (IRR=0.46; 95% CI 0.23 to 0.92) lower compared to 63 matched patients who did not have a RTM system in their cycler (14). Another study of 269 PD patients who received an intervention of daily RTM of blood pressure and weight coupled with video conferencing telehealth care showed that the adjusted risk of hospital admission was 46% (OR=0.54; 95% CI 0.33 to 0.89) lower and hospital days was 54% (OR=0.46; 95% CI 0.26 to 0.81) lower compared to before the intervention (15). It has been estimated that adoption of RTM systems to monitor PD treatments may also yield some economic benefits to the healthcare system in various countries (13, 15).

The influence of RTM on technique failure rates has not been reported previously in PD, yet the improvements we found are consistent with observations from RTM in the home HD population (16). Notably, technique failure rates in all groups for our analysis were lower than many reports in the literature (17, 18), which could be in part due to our definition of a sustained technique failure event that required >6 consecutive weeks of HD and appropriately did not count technique failures as composite outcomes including death. These findings could also be in part representative of patients included in our analysis being a highly select healthier population compared to the overall PD population. Despite the differences in our technique failure rates with some reports, they are relatively consistent with technique failure rates reported in Japan and Asia that exclude mortality events from the definition (18).

RTM has been suggested to have the potential to improve patient-care team communications, timely interventions, and patient outcomes in PD for more than a decade (19). Despite this, the dialysis population has been known to have barriers to access the internet along with inadequate understanding of online systems (20-22). It is estimated that about 35% to 90% of dialysis patients use the internet (20-22). In our analysis we included 17% of patients from the overall active PD population based on inclusionary restrictions to have created an online account, age ≥18 years, and BMI <65. Prior reports suggest similar adoption with 18% of PD patients in Columbia using a different remote monitoring system incorporated via connected health sensors in the cycler (14). Given PD patients are typically younger, it would be expected that there might be a larger proportion of PD patients with access to the internet. If this is a correct assumption, RTM might have the potential to be used in a larger proportion of the PD population, and as smartphone and computer technology advances and becomes more universally affordable, it could become an option for treatment monitoring in the majority of patients.

Our analysis design that included a group of PD patients who universally had internet access to create a RTM account, along with temporal assessments of outcomes adjusted for confounding variables related to demographics, urbanicity, education, comorbidities, and laboratories, adds to the strength of these findings. The relative age of patients did not differ in PD patients who were non-users versus frequent-users, which was expected given the inclusion of only patients with internet access and the ability to use online applications. The majority of the analysis population (65%) never used the RTM to enter clinical information within 30 days of creating an account online. RTM use groups tended to have a sustained higher or lower pattern of RTM use over time compared to baseline, albeit the frequent-user group had some temporal decreases in entries. Both non-users and moderate-users of the RTM may be specific patient types that could be encouraged and trained to become more active in their care monitoring, and if frequent use is adopted as an adjunct, it may have the potential to yield improvements in outcomes.

Given non-users of RTM were more commonly of a black race, Hispanic, with less education, and a longer dialysis vintage compared to frequent-users, it may be import to target interventions to increase RTM use in patients with these attributes who initially elect to capture their treatment data using an RTM. However, further studies would be needed to test if targeting interventions based on patient profiles would be effective.

The RTM evaluated in this study is an application-based patient and clinician portal that we qualitatively believe required relatively minimal resources to construct, deploy, and maintain, as compared to modem-based systems integrated into cyclers. The flexible ability of the RTM to allow patients to enter records when it works the best for them during/around their treatment, combined with the ability for providers to review patients' entries around their daily workflows may be advantageous attributes of this type of connected health technology. These characteristics of the application-based RTM platform appear to allow it to be rapidly beneficial for the smaller percentage of patients with internet access who adopt RTM and allows for scalability over time.

Although this analysis has many strengths, there are some limitations including the inclusion a sub-group of the PD population who had access to the internet and registered for the RTM online. Therefore, these findings are not anticipated to be generalizable to PD patients without access to the internet. We excluded patients with missing data on covariates to provided groups with equivalent adjustments for comparisons, yet this made our population have a higher representation of patients with a White race and longer dialysis vintage, among other distinctions. Neither the RTM, nor EMR, captured data on interventions performed due to findings from RTM entries, so we are not able to assess if interventions are being performed in a more timely manner before monthly clinic visits. Also, we cannot rule out that the favorable associations of higher RTM use might be due to patients being more engaged and having a higher health literacy. However, given the inclusion requirements of the design and the adjustments for education, these are not clear confounders. It is possible that more use of the RTM could be a driver influencing engagement and literacy, thereby teaching the patient to become more of a partner in their care. However, this concept would require further investigations.

## Conclusions

Our findings suggest frequent use of a RTM application associates with less hospital admissions, shorter hospital length of stay, and lower rates of sustained technique failure requiring HD exposure for more than 6 weeks. It appears prudent for PD care teams and providers to consider adopting RTM applications to better engage patients in their care, recognize and manage potential complications in a timely manner, improve the sustainability on the modality, and improve patient outcomes.

## Disclosures

SC, HH, MRM, JL, LU, FWM are employees of Fresenius Medical Care in the Global Medical Office. CM, JR, DM, DC are employees of Fresenius Medical Care North America. LAU, DM, FWM have share options/ownership in Fresenius Medical Care. FWM has directorships in American National Bank & Trust and is chairman of Pacific Care Renal Foundation 501(c)(3) nonprofit.

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*Authors' contributions*

Sheetal Chaudhuri: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Resources; Supervision; Validation; Visualization; Writing - original draft; Writing - review and editing

Hao Han: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Validation; Visualization; Writing - original draft; Writing - review and editing

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Franklin Maddux: Conceptualization; Methodology; Supervision; Writing - review and editing

*Other contributions*

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**Tables:**

**Table 1: Comparison of baseline characteristics among participants included versus patients excluded due to only missing data for adjustment of event analysis**

| **Cohort** | **Included** | **Excluded due to Missing Variables for Adjustment** | **Included versus Excluded p-value** |
|---|---|---|---|
| Patient Count | 6343 | 4736 | |
| **Demographics** | | | |
| Age (years) | 56.9±15.2 | 57.2±14.7 | 0.310 |
| Males (%) | 57% | 57% | 0.933 |
| Black Race (%) | 23% | 25% | 0.003 |
| White Race (%) | 72% | 68% | <0.001 |
| Other Race (%) | 5% | 7% | 0.008 |
| Hispanic Ethnicity (%) | 10% | 11% | 0.022 |
| Dialysis Vintage (days) | 690 | 472 | <0.001 |
| Alcohol Use (%) | 57% | 57% | 0.934 |
| **Urbanicity** | | | |
| Metropolitan (%) | 81% | 83% | 0.028 |
| Micropolitan (%) | 11% | 10% | 0.146 |
| Rural (%) | 8% | 7% | 0.131 |
| **Education** | | | |
| College or beyond (%) | 58% | 58% | 0.972 |
| High School or equivalency (%) | 33% | 32% | 0.654 |
| Less than High School or equivalency (%) | 9% | 10% | 0.507 |
| **Comorbidities** | | | |
| Congestive Heart Failure (%) | 11% | 11% | 0.666 |
| Diabetes (%) | 54% | 54% | 0.983 |
| Ischemic Heart Disease (%) | 13% | 11% | 0.028 |
| **Laboratory** | | | |
| Albumin (g/dL) | 3.55±0.45 | 3.58±0.47 | 0.002 |
| Residual Kidney Function (mL/min) | 4.26±3.32 | 4.67±4.69 | <0.001 |
| Weekly Kt/V | 2.43±1.05 | 2.39±1.04 | 0.113 |

Comparisons between groups were made using t-tests

| Table 2: Baseline characteristics of participants | | | |
|---|---|---|---|
| **Group** | **Non-Users** | **Moderate Users** | **Frequent Users** |
| Patient Count | 4093 | 673 | 1577 |
| **Demographics** | | | |
| Age (years) | 57.6±14.7 | 53.9±15.6*** | 57.9±14.6 |
| Males (%) | 58% | 54% | 58% |
| Black Race (%) | 24% | 23% | 18%*** |
| White Race (%) | 71% | 72% | 76%*** |
| Other Race (%) | 5% | 5% | 6% |
| Hispanic Ethnicity (%) | 11% | 9%** | 6%*** |
| Dialysis Vintage (days) | 732±803 | 553±655*** | 570±732*** |
| Alcohol Use (%) | 24% | 26% | 25% |
| **Urbanicity** | | | |
| Metropolitan (%) | 81% | 79% | 81% |
| Micropolitan (%) | 11% | 13% | 12% |
| Rural (%) | 8% | 8% | 8% |
| **Education** | | | |
| College or beyond (%) | 56% | 64%*** | 60%* |
| High School or equivalency (%) | 33% | 29%* | 33% |
| Less than High School or equivalency (%) | 10% | 7%** | 7%*** |
| **Comorbidities** | | | |
| Congestive Heart Failure (%) | 11% | 10% | 11% |
| Diabetes (%) | 55% | 53% | 54% |
| Ischemic Heart Disease (%) | 12% | 12% | 14% |
| **Laboratory** | | | |
| Albumin (g/dL) | 3.51±0.44 | 3.62±0.44*** | 3.62±0.44*** |
| Residual Kidney Function (mL/min) | 4.26±3.32 | 4.18±3.21 | 4.43±3.40 |
| Weekly Kt/V | 2.42±1.08 | 2.40±0.72 | 2.47±1.12 |
| *Comparisons between groups were made using t-tests. *, P<0.05; **, p<0.01, ***, P<0.001* | | | |

**Table 3: Associations in Adjusted Hospital Admission Rates by Baseline Remote Treatment Monitoring (RTM) Use**

| | 3 Month Admission Count | | 6 Month Admission Count | | 9 Month Admission Count | | 12 Month Admission Count | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **IRR Estimate** | **95% CI** | **IRR Estimate** | **95% CI** | **IRR Estimate** | **95% CI** | **IRR Estimate** | **95% CI** |
| **Moderate-Users** | 0.907 | 0.736-1.120 | 0.922 | 0.775-1.098 | 0.937 | 0.795-1.105 | 0.933 | 0.803-1.085 |
| **Frequent-Users** | 0.775 | 0.662-0.906 | 0.762 | 0.669-0.870 | 0.768 | 0.678-0.871 | 0.737 | 0.657-0.829 |
| **Age** | 1.001 | 0.996-1.005 | 1.001 | 0.997-1.005 | 1.001 | 0.997-1.004 | 1.001 | 0.998-1.004 |
| **Females** | 1.070 | 0.934-1.226 | 1.131 | 1.009-1.268 | 1.057 | 0.947-1.178 | 1.062 | 0.961-1.172 |
| **Black Race** | 0.989 | 0.849-1.153 | 0.970 | 0.854-1.102 | 0.890 | 0.787-1.006 | 0.878 | 0.785-0.983 |
| **Other Race** | 0.770 | 0.559-1.059 | 0.714 | 0.543-0.939 | 0.665 | 0.511-0.865 | 0.598 | 0.465-0.770 |
| **Hispanic Ethnicity** | 1.007 | 0.813-1.247 | 0.968 | 0.808-1.160 | 0.870 | 0.737-1.038 | 0.874 | 0.744-1.026 |
| **Comorbidity: Congestive Heart Failure** | 1.302 | 1.094-1.548 | 1.351 | 1.170-1.560 | 1.302 | 1.133-1.498 | 1.228 | 1.078-1.399 |
| **Comorbidity: Diabetes** | 1.244 | 1.090-1.417 | 1.237 | 1.109-1.379 | 1.215 | 1.096-1.348 | 1.239 | 1.126-1.362 |
| **Comorbidity: Ischemic Heart Disease** | 1.229 | 1.037-1.456 | 1.158 | 1.003-1.338 | 1.157 | 1.008-1.328 | 1.153 | 1.015-1.308 |
| **Albumin** | 0.508 | 0.444-0.581 | 0.513 | 0.458-0.574 | 0.516 | 0.463-0.575 | 0.518 | 0.469-0.573 |
| **Residual Kidney Function** | 0.982 | 0.953-1.012 | 0.984 | 0.959-1.009 | 0.977 | 0.954-1.001 | 0.978 | 0.957-1.000 |
| **Weekly Kt/V** | 0.912 | 0.802-1.038 | 0.878 | 0.783-0.985 | 0.897 | 0.806-0.999 | 0.912 | 0.829-1.004 |
| **Dialysis Vintage** | 1.000 | 1-1.0001 | 1.000 | 1.000-1.000 | 1.000 | 1.000-1.000 | 1.000 | 1.000-1.000 |
| **Education: College or beyond** | 0.902 | 0.731-1.114 | 1.226 | 0.820-1.178 | 1.006 | 0.845-1.196 | 1.138 | 0.873-1.200 |
| **Education: High School or equivalency** | 0.988 | 0.795-1.227 | 0.963 | 0.892-1.295 | 1.088 | 0.910-1.300 | 0.999 | 0.921-1.278 |
| **Alcohol Dependency: Declined to answer** | 0.695 | 0.237-2.032 | 0.983 | 0.270-1.655 | 0.941 | 0.457-1.938 | 1.023 | 0.597-2.016 |
| **Alcohol Dependency: No** | 0.977 | 0.846-1.129 | 1.075 | 0.835-1.060 | 0.973 | 0.868-1.091 | 1.084 | 0.842-1.037 |
| **Urbanicity: Metropolitan** | 1.201 | 0.951-1.517 | 0.669 | 1.006-1.494 | 1.162 | 0.965-1.400 | 1.097 | 0.960-1.347 |
| **Urbanicity: Micropolitan** | 0.908 | 0.673-1.227 | 0.940 | 0.749-1.237 | 1.004 | 0.796-1.267 | 0.934 | 0.808-1.234 |

*Reference Groups: Non-Users, Males, White Race, Education: No High School, Alcohol Dependency: Yes, Urbanicity: Rural*

*IRR = Incidence Rate Ratio*

*Hospital Admission Rates are adjusted by all parameters listed in the table*

**Table 4: Associations in Adjusted Hospital Day Rates by Baseline Remote Treatment Monitoring (RTM) Use**

| | 3 Month Day Count | | 6 Month Day Count | | 9 Month Day Count | | 12 Month Day Count | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **IRR Estimate** | **95% CI** | **IRR Estimate** | **95% CI** | **IRR Estimate** | **95% CI** | **IRR Estimate** | **95% CI** |
| **Moderate-Users** | 0.893 | 0.559-1.426 | 0.951 | 0.692-1.307 | 0.887 | 0.663-1.185 | 0.883 | 0.677-1.152 |
| **Frequent- Users** | 0.618 | 0.424-0.902 | 0.654 | 0.505-0.846 | 0.657 | 0.524-0.824 | 0.680 | 0.554-0.834 |
| **Age** | 1.005 | 0.994-1.015 | 1.005 | 0.998-1.012 | 1.005 | 0.999-1.011 | 1.006 | 1.001-1.012 |
| **Females** | 1.055 | 0.781-1.427 | 1.132 | 0.913-1.404 | 0.992 | 0.829-1.186 | 0.979 | 0.830-1.154 |
| **Black Race** | 0.646 | 0.443-0.944 | 0.767 | 0.598-0.985 | 0.734 | 0.588-0.915 | 0.733 | 0.599-0.898 |
| **White Race** | 0.537 | 0.244-1.183 | 0.567 | 0.329-0.976 | 0.492 | 0.298-0.812 | 0.448 | 0.277-0.723 |
| **Hispanic Ethnicity** | 1.034 | 0.647-1.651 | 0.971 | 0.695-1.359 | 0.886 | 0.656-1.196 | 0.895 | 0.680-1.178 |
| **Comorbidity: Congestive Heart Failure** | 1.310 | 0.886-1.935 | 1.331 | 1.017-1.743 | 1.311 | 1.032-1.667 | 1.249 | 1.001-1.559 |
| **Comorbidity: Diabetes** | 1.391 | 1.032-1.873 | 1.452 | 1.180-1.787 | 1.340 | 1.119-1.607 | 1.305 | 1.107-1.538 |
| **Comorbidity: Ischemic Heart Disease** | 1.110 | 0.754-1.632 | 1.077 | 0.823-1.410 | 1.067 | 0.840-1.354 | 1.068 | 0.859-1.328 |
| **Albumin** | 0.519 | 0.383-0.705 | 0.517 | 0.418-0.460 | 0.480 | 0.398-0.578 | 0.482 | 0.406-0.571 |
| **Residual Kidney Function** | 0.940 | 0.878-1.005 | 0.968 | 0.919-1.018 | 0.942 | 0.909-0.976 | 0.947 | 0.916-0.979 |
| **Weekly Kt/V** | 0.962 | 0.752-1.231 | 0.861 | 0.685-1.080 | 1.006 | 0.923-1.098 | 0.994 | 0.903-1.095 |
| **Dialysis Vintage** | 1.000 | 1.000-1.000 | 1.000 | 1.000-1.000 | 1.000 | 1.000-1.000 | 1.000 | 1.000-1.000 |
| **Education: College or beyond** | 1.293 | 0.778-2.151 | 1.293 | 0.903-1.851 | 1.310 | 0.951-1.803 | 1.303 | 0.976-1.740 |
| **Education: High School or equivalency** | 1.146 | 0.674-1.946 | 1.217 | 0.838-1.763 | 1.283 | 0.922-1.783 | 1.232 | 0.914-1.661 |
| **Alcohol Dependency: Declined to answer** | 0.354 | 0.011-10.943 | 0.393 | 0.041-3.774 | 0.535 | 0.098-2.916 | 0.934 | 0.288-3.036 |
| **Alcohol Dependency: No** | 0.890 | 0.646-1.226 | 0.899 | 0.720-1.122 | 0.986 | 0.808-1.204 | 0.979 | 0.817-1.175 |
| **Urbanicity: Metropolitan** | 1.257 | 0.727-2.173 | 1.287 | 0.878-1.884 | 1.265 | 0.903-1.773 | 1.157 | 0.859-1.559 |
| **Urbanicity: Micropolitan** | 1.110 | 0.565-2.175 | 1.153 | 0.722-1.840 | 1.186 | 0.789-1.784 | 1.164 | 0.812-1.669 |

*Reference Groups: Non-Users, Males, Other Race, Education: No High School, Alcohol Dependency: Yes, Urbanicity: Rural*
*IRR = Incidence Rate Ratio*
*Hospital Days Rates are adjusted by all parameters listed in the table*

**Table 5: Associations in Adjusted Sustained PD Technique Failure Rates by Baseline Remote Treatment Monitoring (RTM) Use**

| | 3-month PD Technique Failure | | 6-month PD Technique Failure | | 9-month PD Technique Failure | | 12-month PD Technique Failure | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **Hazard Ratio** | **95% CI** | **Hazard Ratio** | **95% CI** | **Hazard Ratio** | **95% CI** | **Hazard Ratio** | **95% CI** |
| **Moderate-Users** | 0.657 | 0.403-1.071 | 0.763 | 0.544-1.072 | 0.852 | 0.644-1.127 | 0.869 | 0.673-1.123 |
| **Frequent-Users** | 0.671 | 0.481-0.938 | 0.686 | 0.536-0.878 | 0.687 | 0.555-0.850 | 0.726 | 0.598-0.881 |
| **Age** | 1.000 | 0.991-1.009 | 1.001 | 0.994-1.008 | 0.997 | 0.991-1.003 | 0.997 | 0.991-1.002 |
| **Females** | 0.898 | 0.674-1.197 | 0.912 | 0.735-1.131 | 0.825 | 0.683-0.996 | 0.824 | 0.693-0.979 |
| **Black Race** | 0.777 | 0.556-1.088 | 0.917 | 0.723-1.163 | 0.908 | 0.739-1.116 | 0.908 | 0.752-1.096 |
| **Other Race** | 0.390 | 0.160-0.953 | 0.516 | 0.289-0.923 | 0.612 | 0.385-0.972 | 0.560 | 0.360-0.869 |
| **Hispanic Ethnicity** | 0.782 | 0.489-1.250 | 0.880 | 0.625-1.240 | 0.967 | 0.738-1.285 | 0.966 | 0.745-1.252 |
| **Comorbidity: Congestive Heart Failure** | 1.267 | 0.865-1.856 | 1.240 | 0.935-1.645 | 1.188 | 0.924-1.527 | 1.131 | 0.894-1.432 |
| **Comorbidity: Diabetes** | 1.104 | 0.843-1.447 | 1.105 | 0.906-1.349 | 1.064 | 0.896-1.263 | 1.109 | 0.947-1.298 |
| **Comorbidity: Ischemic Heart Disease** | 0.918 | 0.622-1.355 | 1.009 | 0.762-1.336 | 1.062 | 0.833-1.355 | 0.988 | 0.786-1.241 |
| **Albumin** | 0.640 | 0.479-0.854 | 0.640 | 0.516-0.794 | 0.693 | 0.574-0.837 | 0.681 | 0.572-0.810 |
| **Residual Kidney Function** | 1.033 | 0.989-1.078 | 1.016 | 0.974-1.061 | 1.009 | 0.970-1.049 | 1.013 | 0.978-1.050 |
| **Weekly Kt/V** | 0.580 | 0.436-0.771 | 0.578 | 0.456-0.733 | 0.670 | 0.547-0.822 | 0.673 | 0.559-0.810 |
| **Dialysis Vintage** | 1.000 | 1.000-1.000 | 1.000 | 1.000-1.000 | 1.000 | 1.000-1.000 | 1.000 | 1.000-1.000 |
| **Urbanicity: Metropolitan** | 0.803 | 0.531-1.214 | 0.932 | 0.671-1.295 | 0.898 | 0.676-1.193 | 0.915 | 0.703-1.193 |
| **Urbanicity: Micropolitan** | 0.628 | 0.354-1.116 | 0.743 | 0.478-1.153 | 0.745 | 0.511-1.086 | 0.807 | 0.572-1.139 |
| **Education: College or beyond** | 0.668 | 0.445-1.003 | 0.850 | 0.614-1.177 | 0.941 | 0.706-1.255 | 0.946 | 0.728-1.229 |
| **Education: High School or equivalency** | 0.744 | 0.488-1.134 | 0.929 | 0.664-1.301 | 0.991 | 0.736-1.334 | 0.963 | 0.734-1.265 |
| **Alcohol Dependency: Declined to answer** | 0.000 | 0.000-1.18E+187 | 0.000 | 0.000-1.87E+135 | 0.000 | 0.000-1.02E+191 | 0.000 | 0.000-3.05E+172 |
| **Alcohol Dependency: No** | 0.837 | 0.629-1.114 | 0.823 | 1.016 | 0.852 | 0.709+1.023 | 0.811 | 0.686-0.957 |

*Reference Groups: Non-Users, Males, White Race, Education: No High School, Alcohol Dependency: Yes, Urbanicity: Rural*
*Sustained PD Technique Failure Rates are adjusted by all parameters listed in the table*

**Table 6: Associations in Adjusted Sustained PD Technique Failure Rates by Baseline Remote Treatment Monitoring (RTM) Use Among Survivors of the 12 Month Follow-Up**

| | 3 Month Technique Failure | | 6 Month Technique Failure | | 9 Month Technique Failure | | 12 Month Technique Failure | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **Hazard Ratio** | **95% CI** | **Hazard Ratio** | **95% CI** | **Hazard Ratio** | **95% CI** | **Hazard Ratio** | **95% CI** |
| **Moderate-Users** | 0.487 | 0.236-1.003 | 0.578 | 0.351-0.952 | 0.811 | 0.566-1.163 | 0.825 | 0.594-1.145 |
| **Frequent-Users** | 0.749 | 0.494-1.134 | 0.744 | 0.546-1.015 | 0.736 | 0.566-0.958 | 0.793 | 0.627-1.004 |
| **Age** | 0.996 | 0.984-1.008 | 0.998 | 0.989-1.007 | 0.993 | 0.985-1.000 | 0.991 | 0.984-0.997 |
| **Females** | 0.890 | 0.617-1.284 | 0.836 | 0.633-1.103 | 0.737 | 0.582-0.933 | 0.759 | 0.612-0.941 |
| **Black Race** | 0.718 | 0.465-1.109 | 0.842 | 0.620-1.143 | 0.858 | 0.664-1.109 | 0.840 | 0.664-1.063 |
| **Other Race** | 0.354 | 0.112-1.120 | 0.455 | 0.213-0.972 | 0.513 | 0.280-0.41 | 0.461 | 0.258-0.824 |
| **Hispanic Ethnicity** | 0.888 | 0.513-1.538 | 0.808 | 0.524-1.247 | 0.960 | 0.681-1.354 | 0.998 | 0.733-1.360 |
| **Comorbidity: Congestive Heart Failure** | 1.107 | 0.646-1.897 | 1.044 | 0.700-1.556 | 1.092 | 0.783-1.523 | 0.990 | 0.722-1.357 |
| **Comorbidity: Diabetes** | 1.003 | 0.711-1.415 | 1.157 | 0.896-1.495 | 1.076 | 0.869-1.333 | 1.111 | 0.913-1.351 |
| **Comorbidity: Ischemic Heart Disease** | 0.926 | 0.554-1.547 | 0.977 | 0.674-1.415 | 1.076 | 0.792-1.463 | 1.077 | 0.812-1.428 |
| **Albumin** | 0.556 | 0.382-0.807 | 0.587 | 0.444-0.776 | 0.650 | 0.512-0.824 | 0.641 | 0.516-0.796 |
| **Residual Kidney Function** | 1.033 | 0.985-1.083 | 1.021 | 0.972-1.071 | 1.016 | 0.973-1.061 | 1.020 | 0.982-1.060 |
| **Weekly Kt/V** | 0.574 | 0.405-0.815 | 0.572 | 0.428-0.766 | 0.698 | 0.550-0.886 | 0.676 | 0.544-0.841 |
| **Dialysis Vintage** | 1.000 | 1.000-1.000 | 1.000 | 1.000-1.000 | 1.000 | 1.000-1.000 | 1.000 | 1.000-1.000 |
| **Urbanicity: Metropolitan** | 0.702 | 0.419-1.175 | 0.844 | 0.556-1.281 | 0.793 | 0.561-1.120 | 0.800 | 0.580-1.102 |
| **Urbanicity: Micropolitan** | 0.463 | 0.217-0.988 | 0.695 | 0.399-1.209 | 0.712 | 0.452-1.120 | 0.766 | 0.507-1.157 |
| **Education: College or beyond** | 0.694 | 0.413-1.169 | 0.926 | 0.602-1.423 | 1.011 | 0.702-1.455 | 1.052 | 0.754-1.467 |
| **Education: High School or equivalency** | 0.777 | 0.452-1.335 | 1.065 | 0.685-1.658 | 1.073 | 0.737-1.562 | 1.062 | 0.752-1.499 |
| **Alcohol Dependency: Declined to answer** | 0.000 | 0.000->1E+10 | 0.000 | 0.000->1E+10 | 0.000 | 0.000->1E+10 | 0.000 | 0.000->1E+10 |
| **Alcohol Dependency: No** | 0.841 | 0.582-1.215 | 0.862 | 0.656-1.135 | 0.846 | 0.674-1.063 | 0.782 | 0.637-0.960 |

*Reference Groups: Non-Users, Males, White Race, Education: No High School, Alcohol Dependency: Yes, Urbanicity: Rural*
*Sustained PD Technique Failure Rates are adjusted by all parameters listed in the table*

**Figures and Legends:**

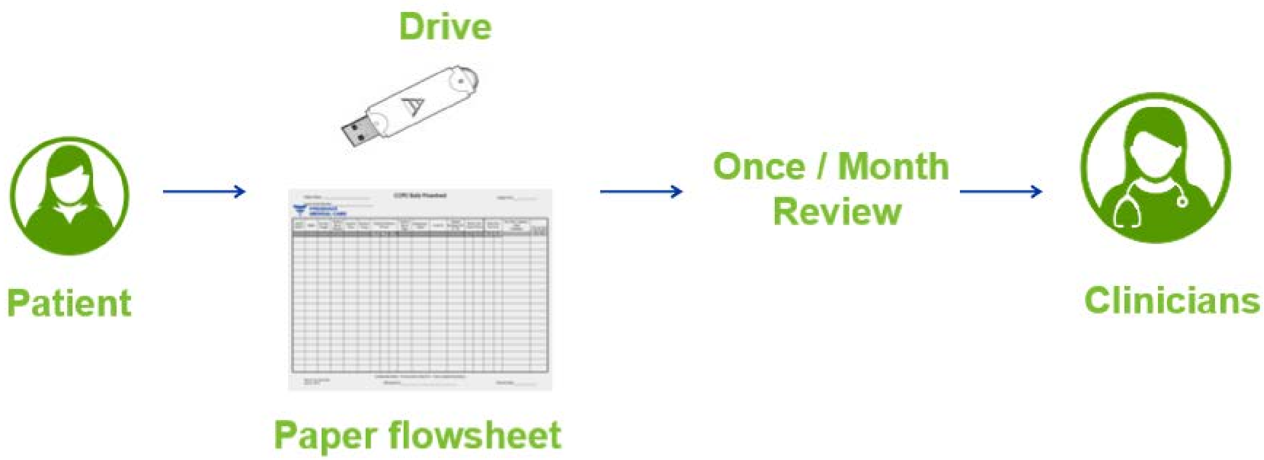
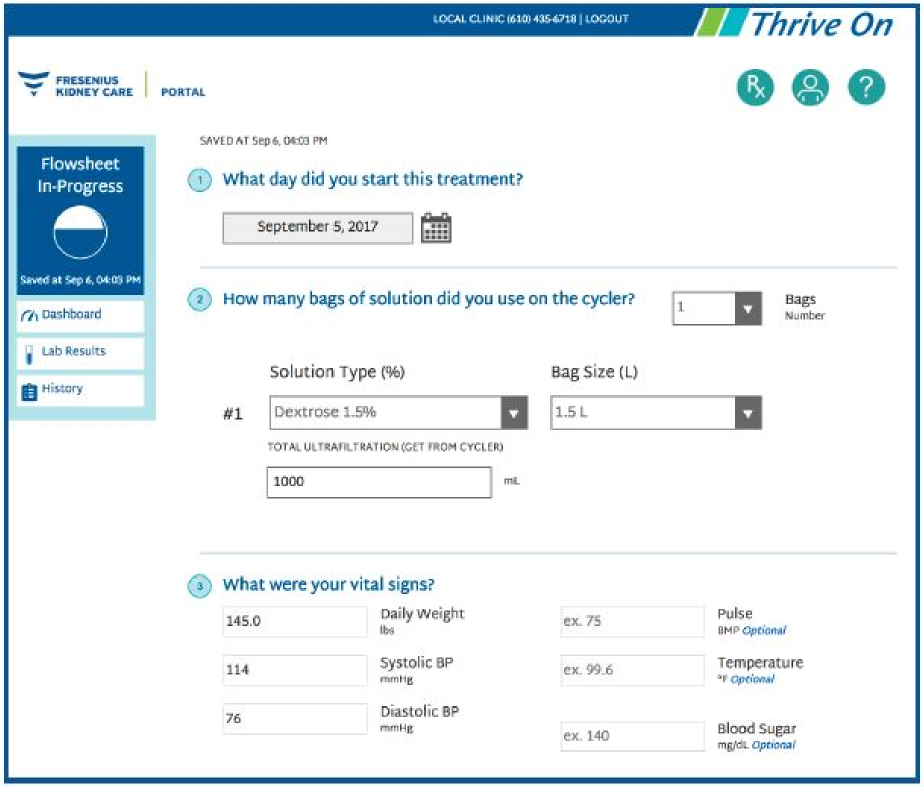



**Figure 1a: Schematic of how the paper flowsheets were submitted manually for review by clinicians once a month**


**Figure 1b: Schematic of how electronic flowsheets are submitted via PatientHub RTM for daily review by clinicians**



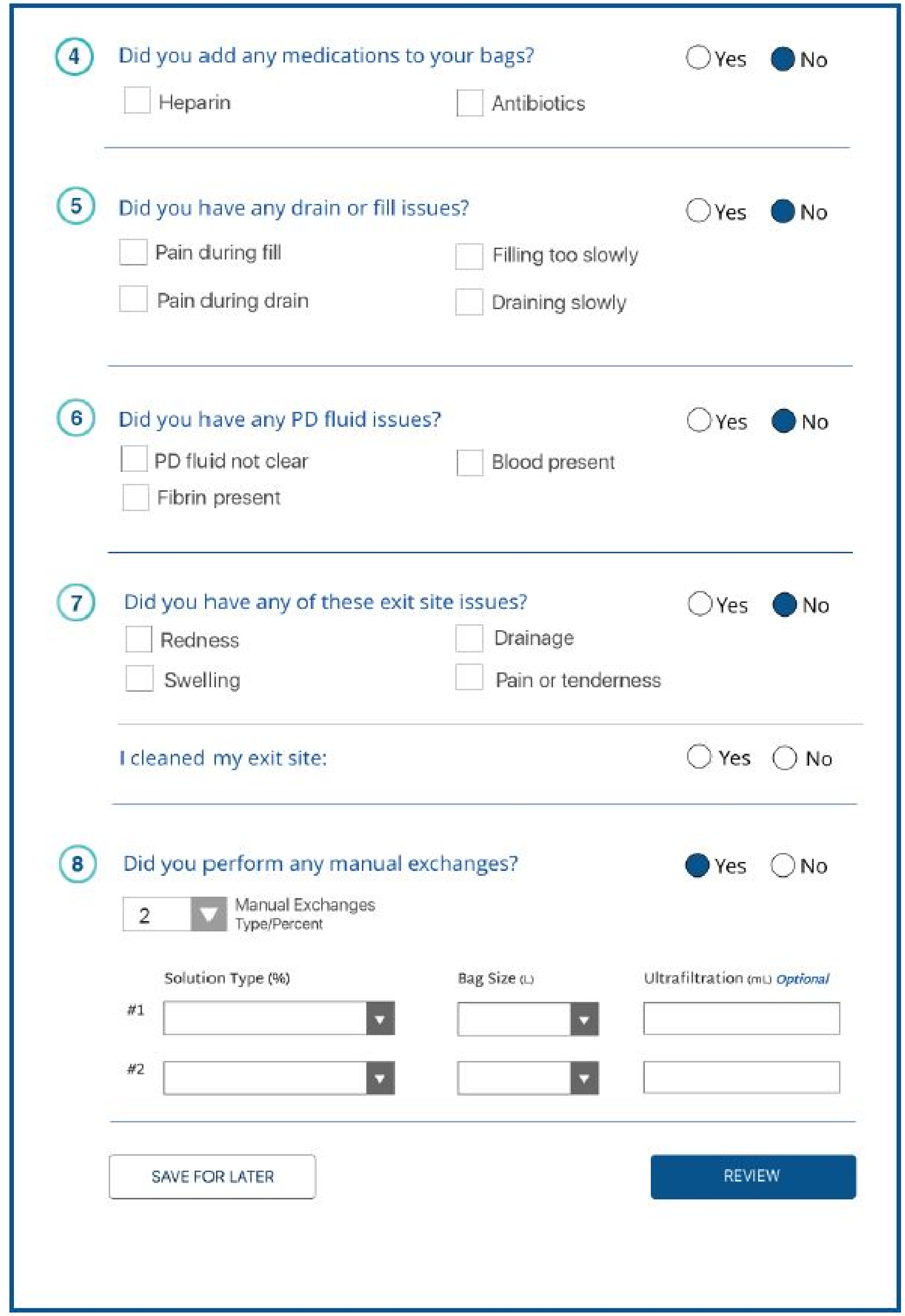
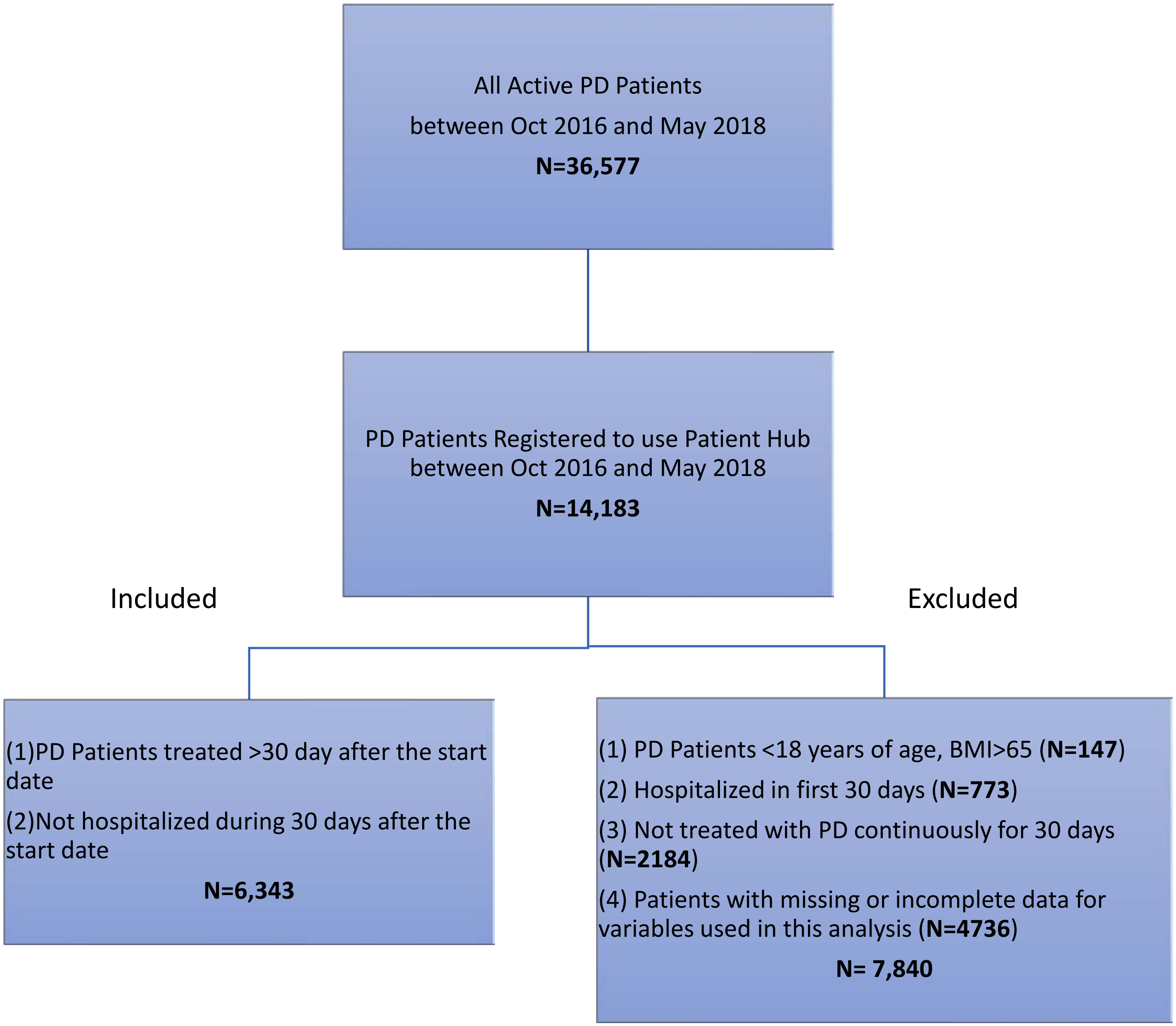




**Figure 2: Preview of the PatientHub RTM application**

**Figure 3: Patient Flow Diagram**



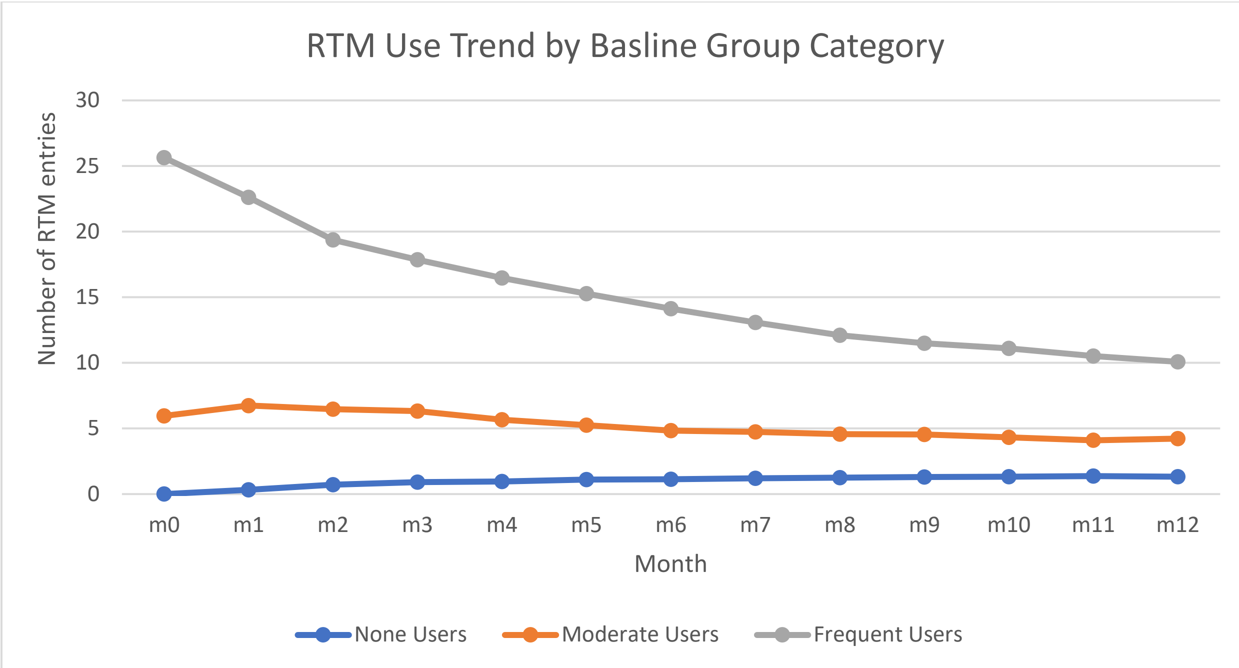



**Figure 4: Trend in the mean number of RTM entries in each month of the follow-up period by baseline RTM use group category**

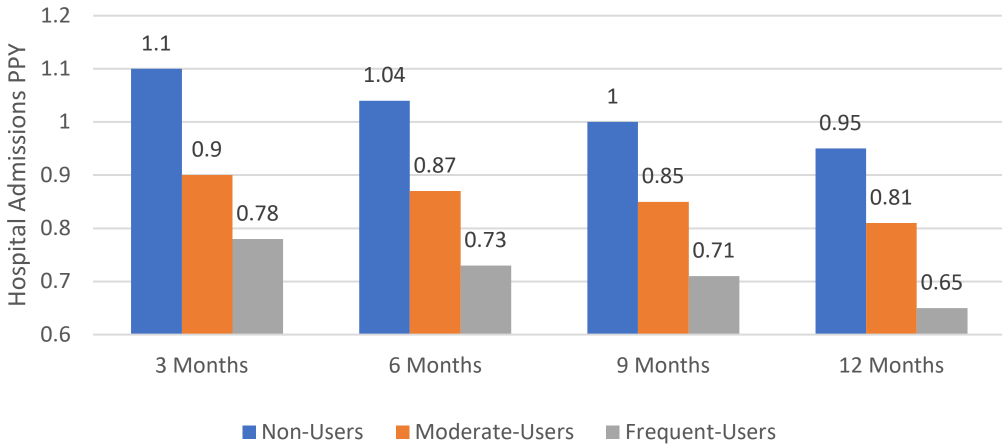



**Figure 5a: Hospital admission rate by baseline RTM use after 3, 6, 9, 12 months of follow-up**

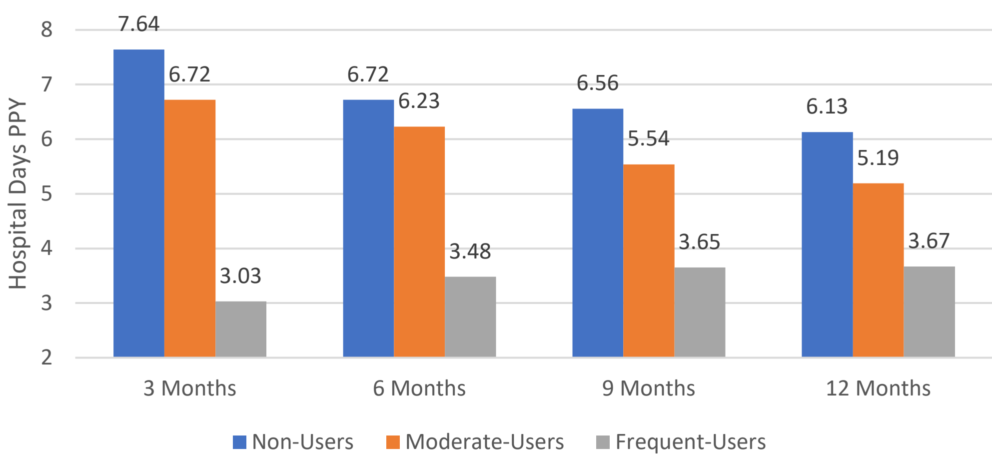



**Figure 5b: Hospital day rate by baseline RTM use after 3, 6, 9, 12 months of follow-up**

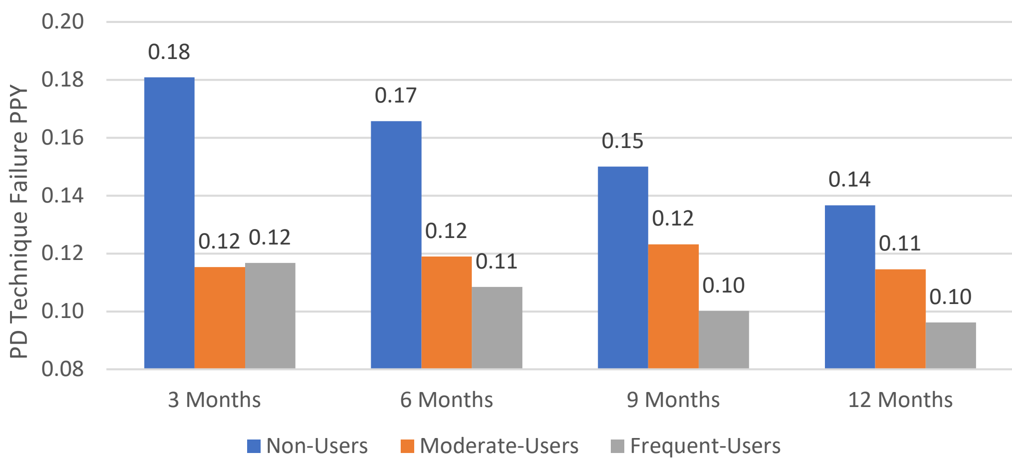



**Figure 6: PD technique failure rate by baseline RTM use after 3, 6, 9, 12 months of follow-up**

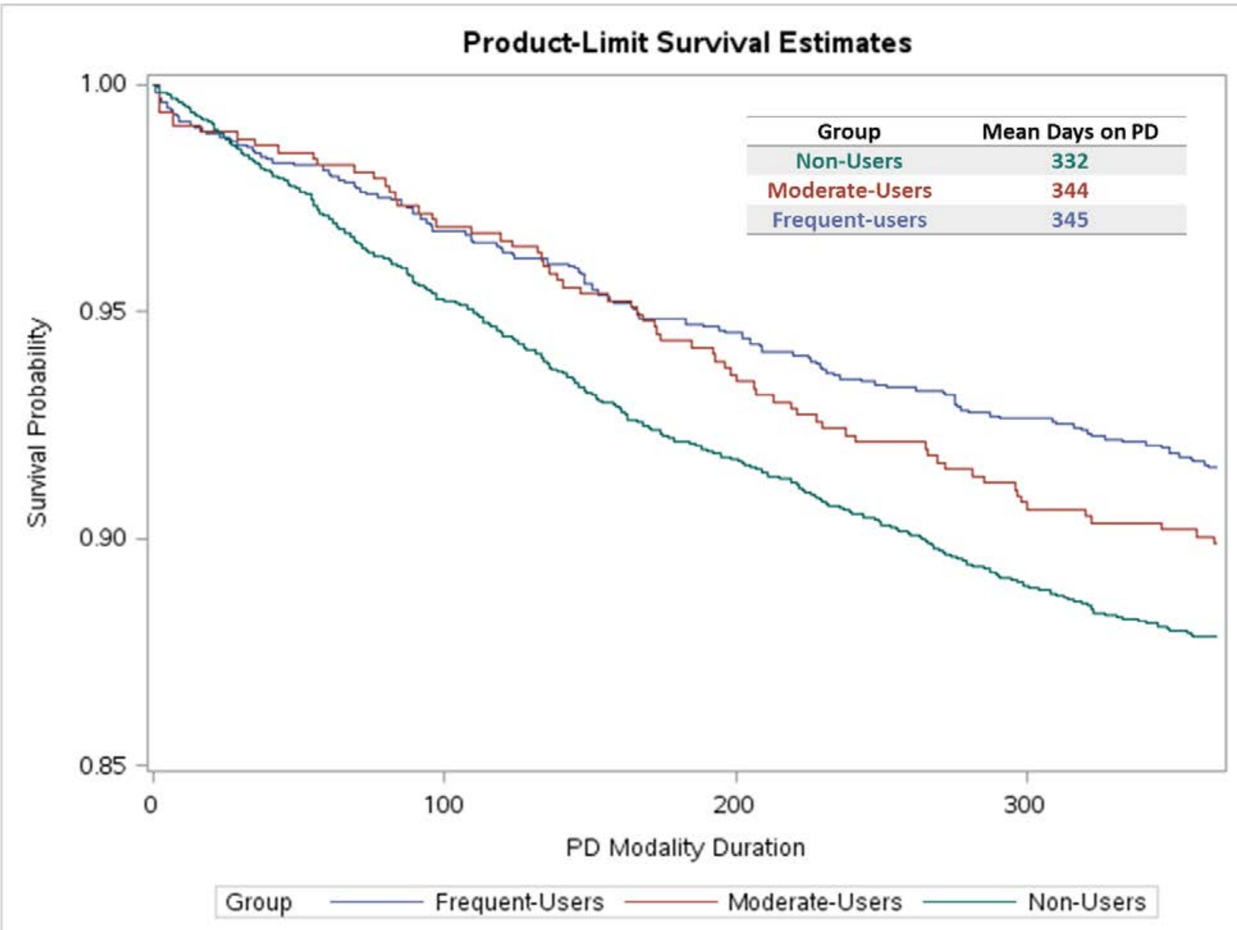



**Figure 7a. Kaplan Meier curve plot to assess the associations in the time on PD modality over the 12 months follow-up for non-users, moderate-users and frequent-users. Frequent-users of the RTM remained on a PD modality 13 days longer in comparison to the non-users group.**

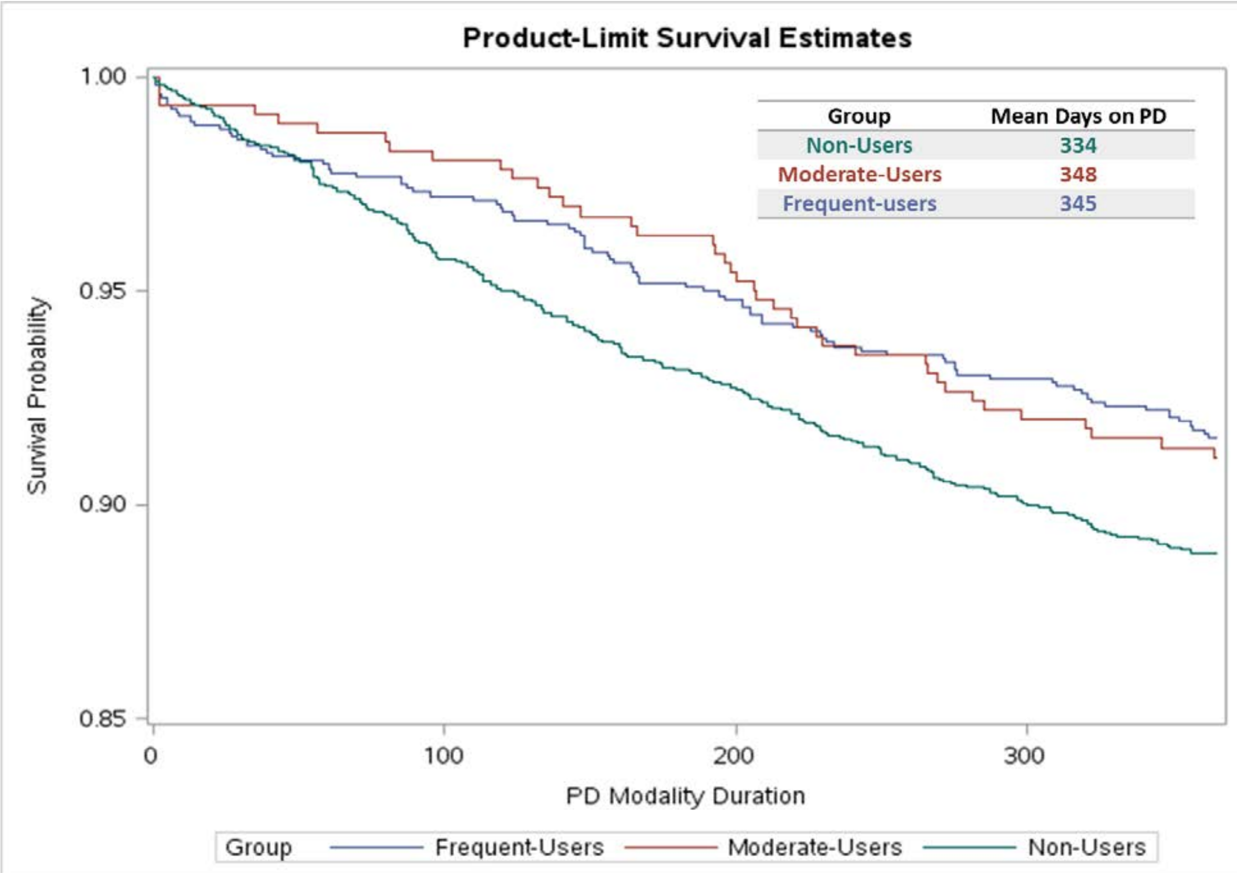



**Figure 7b. Kaplan-Meier plot for survivors of the 12-month follow-up period to assess the associations in technique failure rates and the time on PD modality in a group of patients who had equivalent opportunities to experience a technique failure. Frequent-users of the RTM in the survivor subgroup remained on a PD modality 11 days longer than non-users.**