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Cost analysis of home monitoring in lung transplant recipients

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Objectives: The University of Minnesota has maintained a home monitoring program for over 10 years for lung and heart–lung transplant patients. A cost analysis was completed to assess the impact of home monitoring on the cost of post-transplant medical care.
Methods: Clinical information gathered with the monitoring system includes spirometry, vital signs, and symptom data. To estimate the impact of this system on medical costs, we completed a retrospective analysis of the effects of home monitoring on the cost of post-lung transplant medical care. The cost analysis used multivariate linear regression with inpatient, outpatient, and total medical care costs as the dependent variables. The independent variables for the regression include home monitoring adherence, underlying disease, ambulatory diagnostic group mapping variables, transplant type, and patient demographics.
Results: The multivariate regression of the overall cost results predicts a 52.4 percent reduction in total costs with 100 percent patient adherence; this rate includes a 72.24 percent reduction in inpatient costs and a 46.6 percent increase in outpatient costs. The actual first year average patient adherence was 74 percent.
Conclusions: Adherence to home monitoring increases outpatient costs and reduces inpatient costs and provides an overall cost savings. The break-even point for patient adherence was 25.28 percent, where the net savings covered the cost of home monitoring. This is well within the actual first year adherence rates (74 percent) for subjects in the lung transplant home monitoring program, providing a net savings with adherence to home monitoring.

Keywords: Lung transplantation, Home monitoring, Cost analysis

Lung transplantation has provided patients with end-stage lung disease a treatment alternative with the opportunity to improve survival (8;12) and quality of life (10;15;16;21;22;24). Patient survival is reduced by the development of chronic rejection and infection and provides a significant area of concern for patient follow-up (12). The development of reduced pulmonary function is often an early signal of infection and rejection episodes and provides additional information beyond normal vital sign and symptom monitoring (4;20). Previous studies have shown that home monitoring systems can provide early diagnostic information regarding infection and rejection episodes and may help prevent long-term transplant dysfunction (28). Home monitoring of lung transplant recipients can detect chronic rejection at an earlier time than normal clinical follow-up (7). However, the cost impact of home monitoring for transplant recipients has not previously been evaluated. Previous studies on the cost-effectiveness of lung transplantation have had variable results with a range of $71,000 to $177,000 per quality adjusted life year (QALY) (1;22;27). These results suggest higher costs than have been estimated for other types of solid organ transplants (10). Home monitoring for lung transplant recipients is a relatively new level of care and thus

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has not been a part of previously reported transplant cost studies.

Because cost results may be influenced by age, gender, and medical comorbidities, it is important to adjust for patient case mix. The ambulatory care grouping (ACG) was developed using the International Code of Diseases, Version 9 (ICD-9) codes to create risk profiles for patient case mix assessment (23). The mapping is a multiple step process where ICD-9 codes are mapped to ACG data subset components. Once the patient data have been mapped, the lowest level ambulatory diagnostic group (ADG) mappings are able to explain the greatest variance in patient medical utilization.

The purpose of this study is to assess the cost of home monitoring within the overall context of lung transplantation and to consider the degree of home monitoring adherence needed for the overall effort to be cost-effective. Patient demographics and ADG case mix adjustment will be used to factor in relative disease burden in the population.

METHODS

This cost analysis is a retrospective evaluation of the costs incurred after lung transplantation, including inpatient, outpatient, and home monitoring costs. All transplant recipients who have participated in the University of Minnesota lung transplant home monitoring program (LTHMP) were candidates for the cost analysis study (6). All LTHMP participants provided informed written consent, as approved by the University of Minnesota Institutional Review Board. Several exclusion criteria were used to determine the final study population. To allow a sufficient time for monitoring to be able to establish a medical impact, only patients who were monitored for at least 1 year were included, with the average patient having 3.86 years (SD = 1.9 years) of monitoring. Patients in the first year of the LTHMP who did not receive training in the Patient Learning Center (PLC) were excluded because they had a different device training background that may affect adherence (9). Patients who were re-transplanted were also excluded because they have had a different clinical experience and cost profile than the other transplant patients.

Subjects

There were 148 home monitoring patients meeting the basic inclusion and exclusion criteria. This number included sixty-seven males and eighty-one females, with an average age of 47.7 years (range, 15–65 years). The diseases leading to transplantation include chronic obstructive pulmonary disease (43.9 percent), alpha-1-antitrypsin deficiency (13.5 percent), cystic fibrosis (12.2 percent), idiopathic pulmonary fibrosis (9.5 percent), primary pulmonary hypertension (8.8 percent), and other diseases (12.1 percent). The types of transplant procedures include single lung (55.4 percent), bilateral sequential (38.5 percent), and heart/lung (6.1 percent).

Home Monitoring Data

Subjects performed forced vital capacity maneuvers to obtain pulmonary function information and recorded vital signs and symptoms using an electronic spirometer/diary home monitoring device (17). The primary pulmonary measures include forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), the peak expiratory flow rate (PEFR), and mid-range expiratory flow rates (FEF_{25-75}). In addition to spirometry data, patients recorded weight, pulse, temperature, blood pressure, and respiratory symptoms, including frequency of coughing and wheezing, amount and color of sputum, shortness of breath at rest and after exercise, exercise time and activity, and level of stress and well-being. Subjects were asked to do monitoring daily and to download their daily readings once each week to the study data center using their regular telephone service. The data were placed into a database and stored in a table with one record per day of readings.

Cost Data Components

Of the 148 eligible patients, 145 had complete charge data in the medical claims and 138 had complete payment and charge data. The group of 138 patients with complete claims data provided the population for cost analysis. Payment data best reflected the actual medical costs and provided the basis for the cost analysis.

The cost analysis uses home monitoring, demographic, clinical, and claims data. Administrative claims information for inpatient stays and outpatient follow-up includes data on costs, charges, payments, and ICD-9 code information as well as the dates of patient admission and discharge. These data were obtained from medical claims data. The cost component used for this analysis is the payment received for billed events. Charge values were not used for cost analysis because the charge values did not reflect actual medical care costs or the levels of reimbursement. However, the charge values did provide data for testing payment value validity. Payment to charge ratios and absolute payment values related to contracting approached zero for contracted providers and were not considered valid for cost analysis.

To provide a comparable value, the medical payment totals for each patient were divided by the number of years of survival post-transplant. Medical costs include inpatient hospital and outpatient clinic costs but do not include outpatient medication costs. The outpatient medication costs are likely to be similar for most patients because there is not a large variation in immunosuppressive medication regimens; therefore, it is reasonable to exclude these costs from the analysis. The composite values are placed into the cost analysis regression to assess the effect of home monitoring on the cost of post-transplant medical care. A significant issue for the cost analysis is the underlying variation in disease burden for each patient. Therefore, the cost analysis was adjusted for case mix. The ADG variables reflect the patient case mix and

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are included in the cost regressions. The presence or absence of each disease cluster, along with the age and sex, are used to classify a subject into one or more ADG categories. The subject's ICD-9 codes from the billing data provide the basis for the ADG mapping. As a result, when subjects have a higher number of unique ICD-9 codes they can potentially be assigned to more ADG groups. ADG coding software was used to assign the ADG codes for each subject based on ICD-9 codes identified in the medical claims data (23).

Adherence Definition

Weekly home monitoring adherence is defined as a function of adherence weeks, excused weeks and total potential adherence weeks. A subject is considered to be adherent for a week if he/she sends at least one set of home monitoring data. The total possible adherence weeks include all weeks in which a subject could have taken readings while in the study. The total adherence weeks include all weekly readings taken by the subject and recorded in the database. The excused weeks deduct from the total potential adherence weeks. Possible excuses include hospitalization, vacation, and spirometer device mechanical or transmission problems. Nonadherence is defined as a week where a subject could have provided a reading, but did not record data and did not have an excuse. The basic equation for adherence is as follows:

$$\text{Adherence} = \text{Recorded Readings}/(\text{Possible Readings} - \text{Excused Readings})$$

The calculation produces a value between .0 and 1.0, where .0 is a subject who sends in no data and 1.0 reflects a subject sending in data during each possible time period.

Cost Adherence Analysis

Payment information (inpatient, outpatient, total) was determined to evaluate the relationship between patient adherence and payments. The results were graphed with payments against subject adherence. The adherence component was aggregated by quartiles to assess the relationship between cost and adherence.

Regression Analysis

Multivariable regression analysis was used to assess the impact of home monitoring adherence, gender, age, underlying disease, and type of transplant on medical payments. The regression analysis used payments as the dependent variable and demographics, ADG assignments, underlying disease, home monitoring adherence, and transplant type as the independent variables. Stepwise regression was used to identify relevant subset variables during forward selection analysis. The inclusion criteria for the ADG, treatment, and demographic variables was a *p* value of less than or equal to .25. Once the relevant variables were identified, backward elimination was used to refine the regression model. Criteria for backward elimination included high *p* values and limited capacity to increase R^2 values. Variables with *p* values greater than .15 were eliminated unless they improved the R^2 values substantially or were required in conjunction with the interaction variables in the regression analysis.

Cost Analysis

Given the fixed and recurrent costs of home monitoring, it is useful to assess the specific cost of the home monitoring program with relation to the overall cost impact of home monitoring on post-transplant costs of care. The operational costs of home monitoring were analyzed and compared against the cost savings to find if a true cost savings was generated. Fixed costs were identified for home monitoring initiation. Recurrent costs were also identified that supported home monitoring operations. The aggregate inpatient and outpatient payments are also calculated to provide a basis for the cost analysis.

RESULTS

Adherence Results

The comparison of patient adherence to the costs of care is shown in Figure 1. As subject adherence increases, the cost of inpatient and total medical care is significantly reduced and the cost of outpatient care rises slightly. The results are not adjusted for underlying disease state, or demographic or treatment variables.

The regression model for total payments involved a log transformation of the data. The model was then reduced to relevant results (Table 1). Because the dependent variable has been log transformed, the results provide a percentage change for the costs of medical care.

Specific ADGs influenced the costs associated with post-transplant care. Specifically, ADG03, ADG04, ADG17, and single lung transplant increase the total payments; while ADG26, home monitoring adherence and the ADG03 single

Table 1. Linear Regression of Log of Total Payment

Variables	Coefficient	*p* value
Constant	8.96408	.0000
Patient adherence	−.52433	.0490
ADG03: Time limited major illness	.91636	.0002
ADG04: Time limited major primary infection	.97905	.0000
ADG17: Chronic specialty: unstable ear, nose, throat	1.00508	.0276
ADG26: Signs/symptoms: minor	−.32407	.1364
Single lung TP patients	.59227	.0062
Interaction: Single lung TP/Time Limited Major Illness	−.83247	.0269
R^2	.3371	
Adjusted R^2	.3012	

ADG, ambulatory diagnostic group; TP, transplant.

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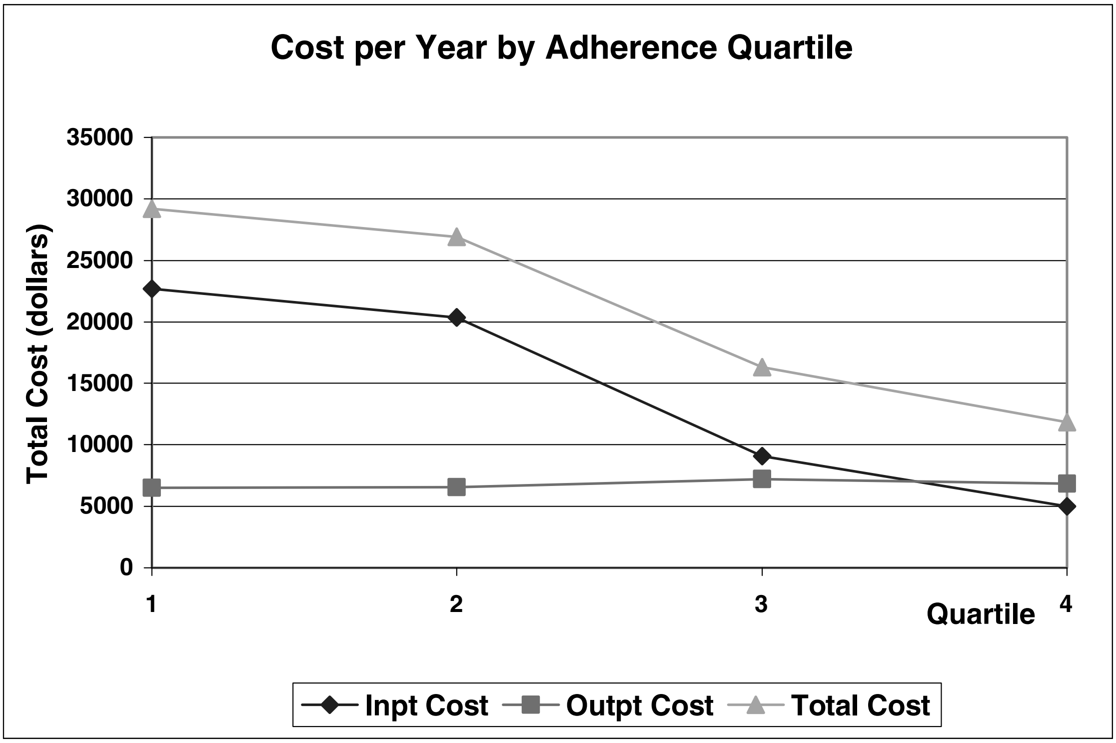

Figure 1. Post-transplantation payments versus home monitoring adherence.

lung transplant interaction reduce total payments. ADG03 includes patients with acute renal failure, bleeding, and lung graft disease. ADG04 includes fungal and bacterial infections. ADG17 is associated with chronic sinus infections. ADG26 includes minor symptoms that are evaluated by a medical provider. Although ADG26 had a relatively high p value, its inclusion improved the model's R^2 value.

The multivariate regression results for outpatient payments are summarized in Table 2. In the outpatient regression, the payment costs are reduced with the presence of ADG08 (discrete infections). Payment costs are increased by home monitoring adherence, heart-lung transplant, ADG01 (dermatological conditions and acute stomach viruses), ADG09 (heart and cerebral vascular disease), ADG10 (bronchitis and chronic obstructive pulmonary disease [COPD]), ADG12 (joint disease), ADG17 (chronic sinus infections), and ADG22 (antibiotic problems). Although ADG17 and ADG22 had a relatively high p values, their inclusion improved the model's R^2 value.

The inpatient payment multivariate regression is summarized in Table 3. Inpatient costs are increased in patients with ADG04 (infections) and ADG09 (cardiac and cerebral vascular disease). Inpatient costs are reduced in patients with

Table 2. Linear Regression of Log of Outpatient Payment

Variables	Coefficient	p value
Constant	7.90686	.0000
Patient adherence	.46615	.0199
ADG01: Time limited minor	.39093	.0626
ADG08: Likely to recur: discrete infections	−.56455	.0367
ADG09: Likely to recur: progressive	.46862	.0372
ADG10: Chronic medical: stable	.38761	.0099
ADG12: Chronic specialty: stable orthopedic	.94399	.0751
ADG17: Chronic specialty: unstable ear, nose, throat	.46708	.1589
ADG22: Injuries/adverse effects: major	.48510	.1651
Patients with heart–lung transplant	.73548	.0029
R^2	.2738	
Adjusted R^2	.2224	

ADG, ambulatory diagnostic group.

Table 3. Linear Regression of Log of Inpatient Payments

Variables	Coefficient	p value
Constant	10.8107	.0000
Patient adherence	−.72235	.0468
ADG04: Time limited major illness–primary infection	.92204	.0003
ADG09: Likely to recur: progressive	1.07828	.0049
ADG11: Chronic medical: unstable	−1.51255	.0046
ADG28: Signs/symptoms: major	−.61630	.0156
Other diseases variable	−.71785	.0614
R^2	.3286	
Adjusted R^2	.2807	

ADG, ambulatory diagnostic group.

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Table 4. Home Monitoring Operational Cost Components

Non-recurring costs	Cost per patient
Home monitoring device	$2,000
Cost of home monitoring training	$70
Non-recurring cost total	$2,070
Recurring costs	Cost per patient
Online costs	$240 per year
Device maintenance costs	$120 per year
Paper and mouthpiece costs	$80 per year
Data reporting costs	$120 per year
Nurse review time	$175 per year
Recurring cost totals	$735 per year

home monitoring adherence, ADG11 (COPD and cystic fibrosis complications), ADG28 (anemia and unspecified lung disease), and "other" underlying disease, which includes a variety of pulmonary diseases.

The costs of home monitoring operations were assessed to provide comparison data between the cost savings of home monitoring versus the cost of its operation. Summary data on the costs of home monitoring are included in Table 4. The average post-transplant outpatient payments were $6,755 per year, the average inpatient payments were $14,405 per year and the average total payments were $21,160 per year. The estimated nonrecurring or fixed cost is approximately $2,070 per device per patient enrolled in the home monitoring program. The ongoing use of the device provides an additional recurring cost of $735 per patient each year for system operations.

DISCUSSION

There are three key findings of the study. The primary finding is decreased overall payments for medical services with increased home monitoring adherence, when adjusted for patient case mix (Table 1). The other key findings are an increased level of outpatient costs (Table 2) and a reduction of inpatient costs as home monitoring adherence increases (Table 3). These results provide evidence of a shift of care from the more expensive inpatient setting to the lower cost outpatient setting. The regression results also provide quantification on the degree of cost savings. The average payment total for the post-transplant subjects is $21,160 per year. The difference in total costs per year for subjects with full home monitoring adherence compared against complete nonadherence, with all other variables constant, is $11,095. Using a fixed cost of home monitoring of $2,070, the recurring cost of operation of $735, and a cost reduction coefficient of 52.43 percent with 100 percent adherence (Table 1), the level of patient adherence required to cover fixed costs is 18.66 percent. The level of adherence needed to cover the recurring costs is 6.62 percent. Because the results provide a cost savings and likely a net cost savings, the use of home monitoring has significant evidence for use in post-lung transplant patient care.

The results of the cost analysis are consistent with prior lung transplant findings. Previous observations by Wagner and colleagues speculated on the potential for home monitoring to shift care of lung transplant patients from the inpatient to the outpatient setting (28). Some of the cost savings may be related to earlier detection of rejection and disease states predisposing patients to rejection. Earlier recognition of chronic rejection has previously been noted with the use of home monitoring (7).

There have not been previous cost analyses on the use of home monitoring in the lung transplantation population. However, home monitoring has been evaluated in other areas of medical management. In particular, asthma care has been managed with the use of home spirometry. Home monitoring has been shown to be viable and can reduce patient morbidity and help improve respiratory parameters in asthmatic patients (11;14). Home telemedicine systems have also been shown to be cost-effective for providing pulmonary medical care (3). Disease state management programs have provided improvements in quality of care and improved medical outcomes for chronic diseases, including diabetes, heart failure, depression, and asthma (5;18;19;25). The use of home spirometry with clinical data review provides a framework on which to provide potential improvements in care quality and cost savings.

Several interesting observations can be drawn from the regression results. In the regression analysis of total payments, the ADG case mix variables and transplant methods affect the medical expenditures. Single lung transplant appears to put patients at increased risk of infection, which may contribute to increased costs. The ADG03 code components, including acute renal failure and bleeding, often require significant medical interventions in the inpatient and/or outpatient settings and thereby increase costs. The exact effects of single lung transplant and ADG03 on cost are difficult to interpret because the transplant variable interacts with ADG03 and the interaction variable demonstrates a cost savings. In addition, ADG04 increases costs and is associated with infections that often necessitate hospitalization and increase the risk of chronic rejection. ADG17, which is associated with chronic sinus infections, likely increases cost by requiring sinus surgeries and extended antibiotic therapy, which may increase the risk of drug resistance. In addition, chronic infections may be a source of pneumonia and other secondary infections, which have high morbidity and mortality in immunosuppressed patients.

Home monitoring adherence is associated with increased outpatient payments. Significant increases in outpatient payments are noted with ADG09, ADG10, heart–lung transplants, and home monitoring adherence. These ADG categories include cardiac, vascular, and respiratory diseases, which increase the cost of care and require significant long-term follow up. Heart–lung transplantation also increases outpatient costs, because both the heart and lungs will require an evaluation of function to assess for rejection and infection.

In the outpatient payment regression, the costs are reduced with the presence of ADG08, which represents discrete infections. These episodes likely represent mild infections that do not need extensive outpatient workups or long-term treatment. Although our data does not allow direct investigation into the cause of this relationship, the increased follow-up visits for the discrete infections may prevent more serious ones, thereby reducing their severity.

Inpatient payments were increased in patients with ADG04 (infections) and ADG09 (heart and vascular disease). Infections are a known major source of morbidity and mortality in lung transplant patients (13). Heart and vascular disease are related to primary lung transplant morbidity factors, including hypertension, renal disease, and hyperlipidemia (12;26).

Inpatient costs are reduced in patients with home monitoring adherence, ADG11 (COPD and cystic fibrosis), ADG28 (unspecified lung disease), and "other" underlying disease. The COPD and cystic fibrosis patient subsets are known to have reduced mortality (26). Negative workups for more severe lung disease likely lead to payment reductions for ADG28. The numbers of patients in the "other" disease category are small in number for each individual particular disease, making it difficult to assess the association with reduced inpatient care costs. Home monitoring adherence likely reduces inpatient payment costs by increasing outpatient interventions, which reduces inpatient care needs.

The results of the study have several limitations. The regression results provide evidence of cost savings due to home monitoring; however, the results of the analysis are limited due to the retrospective design. Since 1992, nearly all patients receiving lung transplants at the University of Minnesota have been enrolled in the home monitoring program. As a result, it would be difficult to do a prospective trial within the system. Comparisons could be completed with centers that do not have home monitoring, but the results would be limited because the care provided and patient populations may be significantly different. The retrospective design also creates a limitation regarding performance bias. The patients who have high adherence to home monitoring may also have high adherence to medications and follow up on medical advice. There is not a good way to control for the bias, but it may impact the strength of the evidence. Evaluation for bias was previously completed with correlation analysis. Routine outpatient clinic post-transplant adherence was compared with home monitoring adherence. No correlation was found; making it less likely that the home monitoring adherence is strongly associated with other types of medical adherence (2). Further evaluation of adherence to outcome points such as medication adherence could better evaluate the impact of performance bias.

An additional limitation of the results is the use of medical claims data. The ability of claims to capture true medical events is limited because it is a secondary data source. Additionally, the costs are not completely captured by the use of claims data. For example, patient time for travel for care, outpatient medication costs, and other indirect medical costs are not captured. However, because these costs are small relative to the costs of transplant care, and because they are likely to affect all patients relatively equally, the exclusion of such data is not likely to impact the final results.

The results of this study provide evidence that home monitoring can reduce the costs of post-transplant care. There are also several directions for future work. Adding additional levels of automation could help to lower the costs and potentially increase the benefit of using the home monitoring system. The home monitoring costs are based on manual review of the home monitoring data. Potential savings may be generated with automation of the data review with a computerized decision support system to make it more cost-effective. Cost reduction could also occur by lowering the cost of the monitoring systems using Web integration and newer technology. The implementation of automated systems also provides the capability to do real-time decision analysis and could thereby improve efficiencies and hasten clinical follow-up. The data can be incorporated into decision systems to provide a disease management program and use home monitoring data to improve clinical care coordination. Although our results show decreasing medical costs with increasing home monitoring adherence, more definitive conclusions would likely result from a prospective study. In designing such a prospective study, more detailed cost diaries would allow us to better categorize direct and indirect medical costs of home monitoring, and their relationship to adherence to the program.

In summary, home monitoring is associated with a cost savings for post-lung transplant patients. This, in combination with our prior findings of early detection of chronic rejection in home monitoring patients, suggests that broader usage of this technology is appropriate. It is likely that further gains in cost could be attained with improved technology to help with data acquisition and analysis such as Web-enabled systems for diary operations and improved home monitoring systems for enhanced data collection.

POLICY IMPLICATIONS

The results of this cost analysis show that home monitoring utilization reduces the cost of post-lung transplant care. The savings provide evidence to support the enhanced use of home monitoring in this population. Consideration of enhanced insurance reimbursement may help to promote the use of home monitoring in the lung transplant population and potentially provide a cost savings for a costly medical intervention. The use of enhanced training and other adherence interventions could also be considered to encourage

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use of the home monitor to help increase system usage and potentially provide cost savings.

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