ARTICLE

Effects of a remote patient monitoring program on cost of care for neonates with inadequate oral feeding

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OBJECTIVE: Remote patient monitoring (RPM) facilitates early discharge of infants with inadequate oral feeding. We aim to determine the financial impact of discharge with RPM compared to continued hospitalization.
STUDY DESIGN: Patients discharged on RPM between May 2019 and June 2024 were eligible. Days of home nasogastric tube feeds and total physician time per episode were recorded. Direct cost estimates for each aspect of RPM and continued hospitalization were used to calculate cost savings of RPM use from a health care system perspective. One- and two-way sensitivity analyses were performed.
RESULTS: One hundred eighty infants were included. RPM decreased the hospital stay by 9.2 days/patient (mean). An RPM episode cost $1,768.24 (mean), while hypothetical continued hospitalization cost $13,978.32 (mean); a difference of $12,210.08. Sensitivity analyses showed that inpatient hospital cost variations were the primary driver of savings.
CONCLUSION: RPM programs for neonates with inadequate oral feeding can reduce direct medical costs.
CLINICAL TRIAL RESGISTRATION: None

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INTRODUCTION

As of 2018, almost 10% of all United States-born infants required admission to a Neonatal Intensive Care Unit (NICU), with a steady increase in the NICU admission rate over recent years [1, 2]. Given the increased utilization of this resource, it is important to understand the cost of NICU care. In 2005, the economic burden associated with preterm birth in the United States was estimated at a minimum of $26.2 billion, or $51,600 per preterm infant [3]. In an evaluation of infants born in California between 2009 and 2011, the mean cost for birth hospitalization ranged from $22,702 for late preterm infants to $317,982 for infants born at <28 weeks gestation [4]. Reducing length of stay has been identified as one method to potentially decrease overuse of NICU resources and reduce cost [5]. Discharge of infants who have inadequate oral feeding (IOF) with nasogastric tube (NGT) feeds is one method of reducing NICU length of stay.

In May 2019, the Doernbecher Children's Hospital (DCH) NICU launched a home NGT feeding program called Growing @ Home (G@H) that utilizes remote patient monitoring (RPM) to discharge infants who have IOF as their only remaining hospital problem [6]. While home NGT feeding programs are proving to be safe and decrease length of stay [6–14], it also has been suggested that such programs could lead to cost savings [13]. From the health care system perspective, we aim to investigate the economic implications of infants sent home on G@H compared to the counterfactual hypothetical cohort of infants who receive ongoing inpatient hospitalization.

METHODS

Sources of costs

Costs assocated with an episode of G@H include RPM vendor/device fees; outpatient appointments with a speech language pathologist, primary care provider, and registered dietician; neonatal provider time; and home health vendor fees. In 2019, our RPM vendor fees included a $1000 initiation fee per patient episode and a $40 RPM device fee. Our institutional contract with the RPM vendor has since changed; this analysis is completed with the initial costs. Costs associated with the various Current Procedural Terminology (CPT) codes were obtained from the Centers for Medicaid and Medicare Services physician fee schedule for the specific locality of Portland, Oregon (year 2024B, accessed September 10, 2024) [15]; non-facility prices were used for ambulatory CPT codes. CPT codes 99457 and 99458 were used to bill for provider time spent on RPM. These are monthly, time-based codes; 99457 accounts for the first 20 min of provider time and 99458 accounts for each additional 20 min of provider time per month. Home health vendor fees, billed monthly, were obtained through personal communication with a frequently used enteral vendor [16].

Costs associated with the counterfactual (i.e. ongoing hypothetical inpatient hospitalization) include the daily facility fee (for a level 2 infant) and the daily professional fee for each additional day of inpatient management. The daily hospital fees for a level 2 NICU patient were based on estimates provided by Oregon Health & Science University from the 2024 fiscal year. The professional fees most commonly associated with these patients are CPT 99479 and CPT 99480; the average of these fees was used in the analysis. Program start-up costs for the institution and salary for the neonatal G@H provider are excluded from this analysis. Parent out-of-pocket costs for direct and non-direct medical care or other expenses for both the NICU stay and post-discharge were not available and thus also

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Table 1. Summary of costs.

Parameter	Cost
Remote patient monitoring vendor initiation and device fee	$1040
Outpatient Speech Language Pathology visit (CPT 92526), non-facility price, single appointment	$88.83
Outpatient primary care provider visit (CPT 99214), moderate complexity, non-facility price, single appointment	$133.67
Outpatient Registered Dietician visit (CPT 97802), non-facility price, single appointment	$38.29
RPM first 20 min (CPT 99457), non-facility, billed monthly	$51.59
RPM each additional 20 min (CPT 99458), non-facility, billed monthly	$40.94
Home health vendor fee, self-pay, billed monthly	$182.50
Level 2 room cost, daily (Oregon Health & Science University, FY24)	$1398
Intensive care, 1500–2500 g, subsequent (CPT 99479), facility price, daily	$121.97
Intensive care, 2501–5000 g, subsequent (CPT 99480), facility price, daily	$117.13

CPT Current Procedural Terminology, 2024B, accessed September 10, 2024.
FY Fiscal year.

not included. Details of the costs used in this analysis are provided in Table 1.

Data collection and economic analysis framework

We undertook a health care system perspective and expressed all costs in 2024 United States dollars. Gestational age at birth and NICU discharge, birth weight and weight at NICU discharge, days of home NGT feeds, days on G@H, and physician time spent per G@H episode were recorded for each patient. Values from Table 1 were applied to the resources to generate a mean [standard error (SE)] and median [interquartile range (IQR)] cost per patient for G@H patients as well as the counterfactual hospitalized patients. One-way and two-way sensitivity analyses were performed by varying all of the cost inputs from 50–400%. Microsoft Excel 2024 was used for descriptive statistics including means with standard deviation and medians with interquartile range (gestational ages, weights, days, physician time), as well as means with standard error and median with interquartile range for total costs.

Study setting and patient population

The DCH NICU is a 46-bed, level-IV unit within Oregon Health & Science University, Oregon's only academic medical center. The NICU has pod-style rooms that hold four to eight infants per room. Of approximately 650 annual admissions, one-third are out-born. G@H has been described previously [6]. Briefly, to qualify for discharge on G@H, infants must (1) be ≥35 weeks' corrected gestational age, (2) weigh ≥2 kg, (3) be able to take ≥30% of daily feeds by mouth, (4) have ≥5 days of cardiorespiratory stability, (5) show consistent weight gain on a stable feeding regimen, and (6) achieve thermoregulation. Parents are taught to insert and maintain the NGT and are provided with all equipment needed for home NGT feeding and RPM support.

Infants were discharged on G@H when they met the above criteria and when the family had received teaching and was comfortable with NGT management and monitoring equipment (which, in addition to standard discharge education, includes successful placement of the NGT a minimum of two times, education on use of the scale and remote monitoring application, and in-person education from the medical equipment vendor). Infants enrolled in G@H were evaluated daily regarding eligibility for NGT removal through data review and telephone conversation between a parent and a neonatal provider. Consistent with clinical practice in the DCH NICU, when G@H infants were able to take at least 80% of their total feeding volume by mouth, they were placed on an on demand (ad lib) feeding schedule. If goal volumes were achieved for 12–24 h, the NGT was removed by the family. The total number of NGT days at home was recorded starting with the first full day at home (the day after NICU discharge). Any NGT feed during a day qualified as a full day of NGT feeds. Standard clinical practice for routine discharge in the DCH NICU requires infants to maintain full oral feeding with weight gain for 48 h after NGT removal. Therefore, for this evaluation, number of hospital days saved by utilizing RPM was determined by adding two days to the number of days that NGT feeds were required in the home. The duration of the RPM episode was determined by parent and provider comfort, and included a minimum of 5–7 days after NGT removal to ensure adequate intake and growth. Physician time spent per day on RPM activities (data review, discussion with parent, documentation) was recorded and totaled for each patient.

All patients discharged on G@H were eligible for inclusion in this analysis. Patients were excluded from this analysis for the following reasons: (1) lost to follow-up, (2) readmitted to the hospital while on G@H and not discharged again on G@H, (3) incomplete data entry, (4) parents did not provide consent for data collection, (5) discharged from G@H still requiring a form of tube feeding, and (6) spent >60 days on RPM working to achieve full oral feeds. The study was approved by the Institutional Review Board at Oregon Health & Science University (#19657). Written informed consent for data collection was obtained prior to discharge from the DCH NICU.

RESULTS

Of 220 babies discharged on G@H between May 2019 and June 2024, 180 are included in this analysis (Fig. 1).

Table 2 describes the cohort in terms of gestational age at birth, birth weight, gestational age at NICU discharge, NICU discharge weight, days of home NGT feeds, estimated hospital days saved, days on G@H, and physician time spent per G@H episode in minutes. The mean and median hospital days saved (9.2 days and 6 days, respectively), as well as the mean and median physician time spent per G@H episode (144 min and 106 min, respectively) are utilized in cost calculations.

Table 3 details the comparison between direct costs associated with discharge on G@H and those associated with continued hospitalization. It also includes estimates of the direct cost savings per G@H patient and for this cohort of 180 G@H patients. The individual costs of G@H are fixed regardless of the length of the RPM episode with the exception of the physician billing, which is based on time spent per month on RPM activities. For this cohort, the mean time spent per RPM episode was 144 min and the median time spent was 106 min. After the initial 20 min of time spent per month, each additional 20 min block of time is billed individually. This results in a direct cost per G@H episode of $1768.24 (SE $16.46) using mean physician time and $1698.64 (IQR $1616.76–$1821.46) using median physician time. The estimated cost of hypothetical continued inpatient hospitalization varies based on whether mean ($13,978.32, SE $937.56) or median ($9105.30, IQR $6070.20–$16,693.05) hospital days saved are used in the analysis.

Using mean data, the direct cost savings per G@H patient is $12,210.08 and for the cohort of 180 patients over 5 years is $2,197,815.06 for the base case analysis.

Sensitivity analyses

One-way sensitivity analyses were performed by varying individual costs by 50%, 200%, and 400% of base case estimates. The

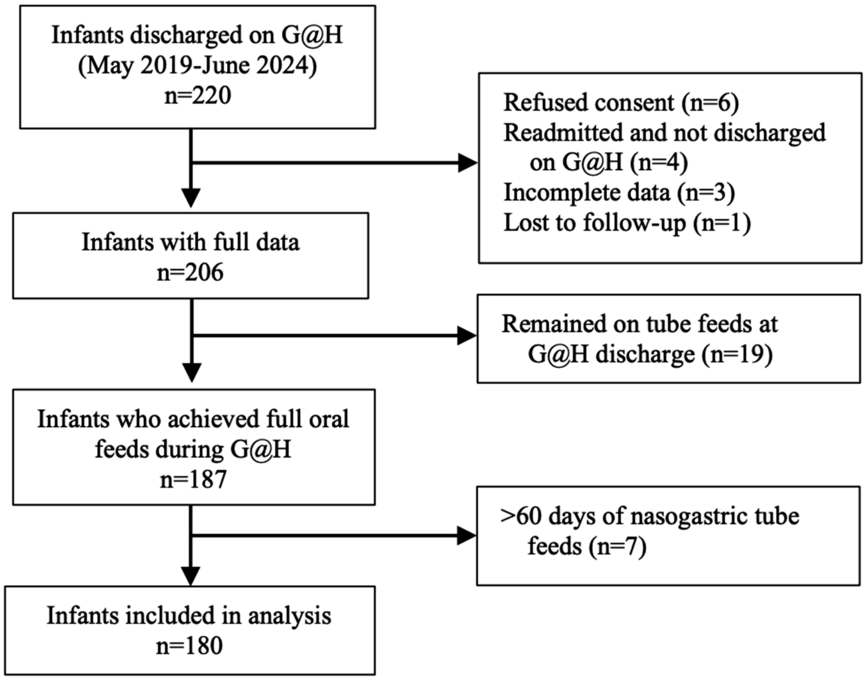

Fig. 1 Flowchart of G@H patients included in the analysis.

Table 2. Descriptive characteristics of cohort ($n = 180$).

Parameter	Mean (SD)	Median (IQR)
Gestational age at birth, weeks	33.2 (3.3)	33.7 (31.3–35)
Birth weight, grams	2085 (768)	2069 (1580–2550)
Gestational age at NICU discharge, weeks	38.5 (2.8)	37.5 (36.3–40)
NICU discharge weight, grams	2975 (693)	2798 (2479–3476)
Days of home nasogastric tube feeds	7.2 (8.3)	4 (2–9)
Hospital days saved, estimated[a]	9.2 (8.3)	6 (4–11)
Days on Growing @ Home	17.4 (10.8)	14 (10–21)
Physician time spent per episode, minutes	144 (107)	106 (75–176)

SD standard deviation.
IQR interquartile range.
NICU neonatal intensive care unit.
[a]days of home nasogastric tube feeds plus 2 days.

largest driver of cost savings was the variation of the inpatient hospital costs for the hypothetical continued NICU stay, with even 50% of the base case cost resulting in savings of $5771 per patient. The cost savings per patient increased when the estimates were inflated for NICU stay and conversely decreased when inflated for the RPM episode (Table 4). Two-way sensitivity analyses revealed the point at which G@H did not result in cost savings occurred when the G@H episode reached 400% of the base case estimate and the hypothetical continued hospital stay cost 50% of the base case estimate (Supplementary Table 1; at this point, staying in the hospital saved $83.79).

DISCUSSION

G@H resulted in significant cost savings per patient enrolled in an RPM episode compared to the counterfactual hypothetical scenario of ongoing NICU care of these patients. The largest driver of cost savings in our analysis is the inpatient room cost.

Historicaly, the physiologic criteria of (1) oral feeding sufficient to support growth (2), achievement of appropriate thermoregulation, and (3) mature respiratory control have been required prior to NICU discharge [17]. Commonly, oral feeding is the final of these to be achieved. Edwards and colleagues [18] showed that 37% of moderately premature infants remain hospitalized at 36 weeks' corrected gestational age due to IOF and the ongoing need for NGT feeds alone. As NGT feeding support is not an intensive-care service and can be provided by some families independently, creation of home NGT programs throughout Europe and the US to support development of oral feeding skills in the home has been one method to facilitate early NICU discharge. Variation exists among the programs, namely in discharge criteria and methods of follow-up; however, outcomes in terms of feasibility and safety are favorable [6–14, 19–23].

G@H utilizes the six aformentioned discharge criteria. Utilizing these criteria, infants with a wide range of birth gestational ages, medical diagnoses, and complexity are discharged on G@H. Though the goal of every infant discharged on G@H is to achieve full oral feeding during the RPM episode, this does not always occur. As we have described, a subset of G@H discharges are infants that utilize G@H to provide a prolonged amount of non-hospital time to either achieve full oral feeds or lead to the decision to have a surgical gastrostomy tube placed. In our original description, 14% of the infants in the cohort required longer than 60 days of home NGT feeds or were discharged from G@H with continued tube feeding. These infants had a higher percentage of additional significant diagnoses (beyond prematurity and IOF) and were discharged at later corrected gestational ages, suggesting higher medical complexity [6]. With this known dichotomy, we focused on the infants who achieved full oral feeds while enrolled in G@H and within 60 days of NICU discharge for this analysis. Thirty infants (13.6%) in this cohort remained on tube feeds beyond the G@H episode, required more than 60 days to achieve full oral feeds, or were readmitted and not discharged on G@H. These 30 patients were born at an average gestational age of 29.9 weeks (SD 3.7 weeks) with mean birth weights of 1397 g

Table 3. Cost comparison.

	Growing @ Home		Continued Hospitalization	
	Mean (SE)	**Median (IQR)**	**Mean (SE)**	**Median (IQR)**
Level 2 room cost, total	N/A	N/A	$12,877.13 ($863.70)	$8,388 ($5592–$15,378)
Professional Fees, total	N/A	N/A	$1101.19 ($73.86)	$717.30 ($478.20–$1315.05)
RPM vendor initiation/device fees	$1040	$1040	N/A	N/A
Outpatient RD, SLP, PCP appointments, one each	$260.79	$260.79	N/A	N/A
RPM billing, initial 20 min	$51.59	$51.59	N/A	N/A
RPM billing, each subsequent 20 min	$233.36 ($16.46)	$163.76 ($81.88-$286.58)	N/A	N/A
Home health vendor fees	$182.50	$182.50	N/A	N/A
Total Cost per Patient	**$1768.24** ($16.46)	**$1698.64** ($1616.76-$1821.46)	**$13,978.32** ($937.56)	**$9105.30** ($6070.20–$16,693.05)
Delta per Patient (mean)	**$12,210.08**			
Total Cost Per cohort ($n = 180$)	**$318,282.84**	N/A	**$2,516,097.90**	N/A
Delta for cohort (mean)	**$2,197,815.06**			

SE standard error.
IQR interquartile range.
RPM remote patient monitoring.
RD registered dietician.
SLP speech language pathologist.
PCP primary care provider.

(SD 692 g). They were discharged from the NICU at an average corrected gestational age of 41.4 weeks (SD 2.6 weeks) and spent an average of 73.3 days (36.9 days) on G@H. Comparing to the 180 infants included in this analysis (Table 2), the excluded infants were younger, smaller, discharged later, and had a longer duration on RPM, suggesting a dfferent level of medical complexity. We recognize we are not capturing a potentially significant cost savings associated with discharge of these patients on RPM; however, due to the variability in their courses, we were unable to accurately estimate how many hospital days were saved by utilizing RPM. Therefore, we are reporting on the majority of our patient population and a population of patients that is easily generalizable to other NICUs across the country.

A unique and advantageous aspect of our home NGT program is the use of RPM. RPM has been shown in various settings to decrease direct costs, and in some conditions, lead to reduced need for admission or clinic visits [24–28]. A growing body of evidence supports use of RPM in home NGT programs for infants [12, 20, 29–32]. While the addition of RPM to our home NGT program does add a cost, we have found that RPM allows us to discharge infants that may have previously been deemed too "high risk" for home NGT feedings (i.e, those who live a great distance from a hospital or those who live in rural settings). The RPM application we use can be downloaded onto a personal device, or if one is not available, a WiFi and cellular-enabled tablet is loaned to the family as a part of the program. With this technology, a remote connection is possible for the vast majoring of families. We have also found that families appreciate the ability to discharge from the NICU as soon as possible while still having the frequent touch points and support from a NICU provider on a routine basis [33, 34].

We report here on the direct cost savings for use of RPM in this patient population, but this does not account for all of the potential economic benefits of early discharge using RPM. Earlier discharge from the NICU with home NGT feeds also leads to cost savings for families. NICU care can place a significant financial burden on families, with an average of over $3000 of out-of-pocket expenses in addition to the hundreds of dollars that is spent on transportation to and from the NICU [35]. While we did not have the ability to directly measure this savings for our cohort of families, our families have reported this as a benefit to G@H [33]. We also acknowledge the potential financial burden that may be placed on the family because of early discharge [36]; we did not have the ability to measure this but in the future this is a consideration in the evaluation of economic implications of early NICU discharge.

Another financial benefit not included in this analysis is that to the hospital itself. Discharge of stable level 2 infants provides the ability to admit critically ill infants at a time when many NICUs are struggling with bed capacity. While dependent on the specific NICU and its patient population, hospital revenue for a new admission will be greater than for continuing the hospitalization of a lower acuity patient.

To our knowledge, this is the first cost analysis performed in the United States for RPM programs for neonatal IOF. The strengths of our research builds on the unique aspects of the G@H RPM program, the generalizability of the patient population, and the five years of experience along with a relatively large sample size. The sensitivity analyses demonstrate that the main driver of the cost savings from using our RPM program is the cost of the level 2 daily facility fee. If the daily facility fee is lower, this has more of an impact on the cost savings per episode of care than if the cost of any other element of the analysis is lower. If the daily facility fee is higher, this has an enormous impact on the savings that can be realized using RPM. Similarly, if the number of hospital days saved is higher (effectively increasing the total of the facility fee), the cost savings of utilizing RPM will be greater.

We must also acknowledge the limitations of this research. As G@H was a clinical program instituted in our NICU for all who qualified, we did not randomize infants to G@H vs. standard care. The lack of randomization led to the necessity of doing this cost comparison utilizing the hypothetical continued inpatient hospitalization. Additionally, this is a single center study that included patients discharged home from a regional level IV NICU. The patient population discharged from a level IV NICU differs from that of a level II or III NICU. We have found that about 10% of our annual admissions end up being eligible for discharge on G@H;

Table 4. One-way sensitivity analyses of cost savings per eligible G@H subject.

Parameters	Savings per eligible G@H subject
Base Case Analysis	$12,210.08
Level 2 room cost	
50%	$5,771.52
200%	$25,087.22
400%	$50,841.47
Professional fees	
50%	$11,659.49
200%	$13,311.27
400%	$15,513.65
RPM fees (vendor and device)	
50%	$12,730.08
200%	$11,170.08
400%	$9,090.08
Outpatient RD, SLP, PCP appts	
50%	$12,340.47
200%	$11,949.29
400%	$11,427.71
RPM billing, 1st 20 min	
50%	$12,235.87
200%	$12,158.49
400%	$12.055.31
RPM billing, each subsequent 20 min	
50%	$12,326.76
200%	$11,976.72
400%	$11,510.00
Home health fees	
50%	$12,301.33
200%	$12,027.58
400%	$11,662.58

G@H Growing @ Home.
RPM remote patient monitoring.
RD registered dietician.
SLP speech language pathologist.
PCP primary care provider.

the percentage of eligible patients would likely be higher in level II or III NICUs. By limiting our evaluation to the typical “feeder and grower” patients that were able to successfully achieve full oral feedings in under 60 days while on RPM, we have created a generalizable population with which almost all NICUs could identify. Third, we utilized costs specific to our center/region in the analysis. While absolute cost savings would be specific to individual NICUs, we feel with the magnitude of cost savings that we have found coupled with the sensitivity analyses, it is reasonable to assume that a similar savings would be realized in other specific locations. Fourth, using the health care system perspective does not capture the financial impact on the family unit. While a tremendous financial burden is placed on families whose infants are in the NICU, we also recognize that shifting that care to the home may generate additional costs. Thus, a societal perspective that captures this impact is critical in future studies. Finally, we do not include the cost of program creation and management in this analysis. The costs to a facility for these aspects of program development will depend on the RPM company utilized, telemedicine infrastructure of the institution, and salary of the personel who manage the program.

We do not include an assessment on the effect on cost savings for readmissions. In this cohort of 180 infants, 5 required readmission while being followed by G@H. None of these readmissions were due to complications of NGT feeds and would have occurred had the patient been home on full oral feeds (reasons for admission: fever, retinopathy of prematurity surgery, blood transfusion in setting of isoimmunization, bronchiolitis, and pyloric stenosis). For this low risk population, we did not feel that inclusion of potential readmission costs in the equation were necessary. Readmission is more likely in the population that was excluded from this study, the majority of whom required longer term tube feeding. This population is inherently slightly more complex than the population included in this analysis. In a future cost analysis of a more complex population, readmission costs should be taken into account.

CONCLUSION

In this group of 180 infants discharged from our RPM program, close to $2.2 million in direct medical costs was saved. We expect that the development of RPM programs like ours in other NICUs will realize similar savings, even accounting for local variations in costs. Future directions include evaluation of cost savings for those infants who do not achieve full oral feeding within 60 days of NICU discharge as well as financial impact of RPM programs on families. In light of the increasing use of NICU resources, cost burden of NICU care nationally, and the changing economic landscape of healthcare, widespread implementation of RPM programs to facilitate early and safe discharge of neonates with IOF has the potential to significantly impact costs nationwide.

DATA AVAILABILITY

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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AUTHOR CONTRIBUTIONS

CRF conceptualized and designed the study, drafted the initial manuscript, and critically reviewed and revised the manuscript. DD conceptualized and designed the study, and critically reviewed and revised the manuscript. JBW conceptualized and designed the study, collected data, carried out the initial analyses, and critically reviewed and revised the manuscript. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

COMPETING INTERESTS

The authors declare no competing interests.

ETHICS APPROVAL

The study was approved by the Institutional Review Board at Oregon Health & Science University (#19657). The study was performed in accordance with the Declaration of Helsinki.

ADDITIONAL INFORMATION

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