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Long-term effects of telemonitoring on healthcare usage in patients with heart failure or COPD ☆

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ABSTRACT

Background: Heart failure and chronic obstructive pulmonary disease (COPD) are leading causes of disability and lead to substantial healthcare costs. The aim of this study was to evaluate the effectiveness of home telemonitoring in reducing healthcare usage and costs in patients with heart failure or COPD.
Methods: The study was a retrospective observational study with a follow-up duration of up to 3 years in which for all participants data before and after enrollment in the telemonitoring program was compared. Hundred seventy-seven patients with heart failure (NYHA functional class 3 or 4) and 83 patients with COPD (GOLD stage 3 or 4) enrolled in a home telemonitoring program in addition to receiving usual hospital care. The primary outcome was the number of hospitalizations; the secondary outcomes were total number of hospitalization days and healthcare costs during the follow-up period. Generalized Estimating Equations were applied to account for repeated measurements, adjusting for sex, age and length of follow-up.
Results: In heart failure patients, after initiation of home telemonitoring both the number of hospitalizations and the total number of hospitalization days significantly decreased (incidence rate ratio of 0.35 (95% CI: 0.26–0.48) and 0.35 (95% CI: 0.24–0.51), respectively), as did the total healthcare costs (exp (B) = 0.11 (95% CI: 0.08–0.17)), all $p < 0.001$. In COPD patients neither the number of hospitalizations nor the number of hospitalization days changed compared to the pre-intervention period. However, the healthcare costs were about 54% lower in COPD patients after the start of the telemonitoring intervention (exp(B) = 0.46, 95% CI 0.25–0.84, $p = 0.011$).
Conclusions: Integrated home telemonitoring significantly reduced the number of hospital admissions and days spent in hospital in patients with heart failure, but not in patients with COPD. Importantly, in both patients with heart failure and COPD the intervention substantially reduced the total healthcare costs.

1. Introduction

Heart failure and chronic obstructive pulmonary disease (COPD) are in the top ten of the most common chronic disorders worldwide.[1–3] They are a leading cause of death and disability and a major burden to society due to substantial healthcare costs

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involved. As the number of people over 60 years of age is expected to almost double in the next 35 years, the healthcare costs related to chronic diseases are also expected to rise.[4] Thus, developing strategies to reduce (re-)admissions of patients with heart failure and COPD is important for both improving quality of life of the patients and reducing healthcare costs.

Telemonitoring is a promising strategy for improving outcomes and reducing healthcare costs in patients with heart failure, COPD and other chronic diseases.[5–10] Home telemonitoring is a technology to monitor patients at home, for example by daily measurements of body weight or blood pressure. This enables early detection of deterioration and allows early intervention which could potentially reduce the number of hospital visits, number of hospitalizations, duration of hospital stays and mortality. Therefore, it is not surprising that telemonitoring has attracted great interest, especially among policy makers, as a potential solution to the global challenge of providing care for the growing number of patients with chronic diseases.

Despite the potential benefits of telemonitoring, robust and unequivocal evidence is still lacking which precludes drawing firm conclusions about its clinical efficacy or cost-effectiveness.[7] Some research suggests that telemonitoring can have a positive effect on patients with chronic diseases, such as improved quality of life,[11] and reduced use of secondary healthcare, including emergency hospital admissions.[12–18] Yet, other studies found either no effect or a negative effect.[19–24] The heterogeneity of telemonitoring interventions in these studies varied widely from 'simple' telephone follow-up to daily monitoring of physiological symptoms with substantive clinical support, which contributes to the difficulty in interpreting the different outcomes. In addition, different studies focused on different patient groups: some studied the effects of telemonitoring only in subjects with COPD, while others focused on subjects with heart failure or diabetes. Moreover, most studies had a relatively short follow-up duration of several months to a year. As patients with most chronic diseases are hospitalized on average only once to twice per year, such a short follow-up duration could make it difficult to detect an effect on the number of hospitalizations or healthcare costs. This heterogeneity among studies has led to calls for further research to clarify the effectiveness of telemonitoring in chronic diseases,[6] such as heart failure and COPD.

To evaluate the effectiveness of home telemonitoring in reducing healthcare utilization and costs in patients with heart failure or COPD, we conducted a retrospective observational study with a follow-up duration of up to 3 years. To our knowledge, this is the first time that the effect of telemonitoring is studied conjointly in two of the most common chronic diseases with such a relatively long follow-up duration.

2. Methods

2.1. Study design

In 2012 the Slingeland Hospital (a large, general, non-academic hospital in Doetinchem, The Netherlands) started a telemonitoring program for patients with COPD or heart failure as part of their usual care. Data were collected between January 2012 and December 2016. The study was approved by the local medical ethical committee of the hospital and all patients provided written informed consent before participation. We conducted a retrospective observational study applying a pre-post research design in which data for all participants before and after enrollment in the program was compared.

2.2. Eligibility and enrollment of patients

Patients were eligible for the telemonitoring program if they had an advanced disease stage (New York Heart Association (NYHA) functional class 3 or 4; COPD Global Initiative for Chronic Obstructieve Lung Disease (GOLD) stage 3 or 4), received treatment for this condition by a cardiologist or pulmonary specialist at the Slingeland Hospital, were proficient in Dutch and capable of providing informed consent (Fig. 1). Exclusion criteria were absence of the cognitive or physical capacity or access to resources required to fully participate in the intervention, lack of an internet connection at home, being admitted to a skilled nursing facility, unwillingness to participate in the study, or being unable to provide informed consent.

2.3. Usual care

The usual care for heart failure and COPD patients at the Slingeland Hospital consisted of routine monitoring through regular check-ups with their specialist at the hospital, either a cardiac or pulmonary specialist. The frequency of check-ups for heart failure patients with severe morbidity is every three months, whereas the frequency of check-ups in COPD patients with severe morbidity is at least every six months, including a general assessment every year. These regular check-ups are not completely structured. In brief, these encounters consist of a review of the complaints, exacerbations and/or hospitalizations since the last contact with the healthcare provider, an evaluation of the current clinical and functional situation, an update of the (pharmacological) treatment if necessary, promoting therapy compliance, reviewing psychological complaints, and a reminder of some recommendations for healthy habits. In addition, in COPD, a patient's inhalation technique might be observed and evaluated.

In between these regular check-ups by a cardiac or pulmonary specialist, the general practioner was responsible for the daily medical care of the patients. This daily medical care was not structured, was designed by the general practitioner and therefore differed among general practitioners. During a hospitalization, the care for the patient was the full responsibility of the medical specialist. After a hospitalization, the daily care for the patient was taken over again by the general practitioner and the check-ups were resumed by the medical specialist according to the original schedule.

2.4. Telemonitoring intervention

The integrated home telemonitoring intervention consisted of at home registration of different measurements via a specially designed application (FocusCura cVitals, CE medical device class I) on a leased electronic touch screen (iPad, Apple Inc. Cupertino, CA, USA). Patients received this care in addition to the usual care from the hospital. A schematic overview of the home telemonitoring intervention is presented in Fig. 2. Upon enrollment, patients were visited at home by a member of staff to provide an explanation and to setup the measurement devices. Phone or video support was available in case of technical issues.

In patients with heart failure the health status was evaluated by daily weight measurements on a scale (iHealth Lite, iHealth Labs Inc. Mountain View, CA, US), and weekly by measurements of blood pressure and heart rate (Omron MIT-5, Omron Healthcare Europe, Hoofddorp, the Netherlands), as well as completion of a symptom questionnaire (Supplementary File 1). The provided scale and blood pressure monitor automatically sent measurements to the application, preventing errors that can occur when patients

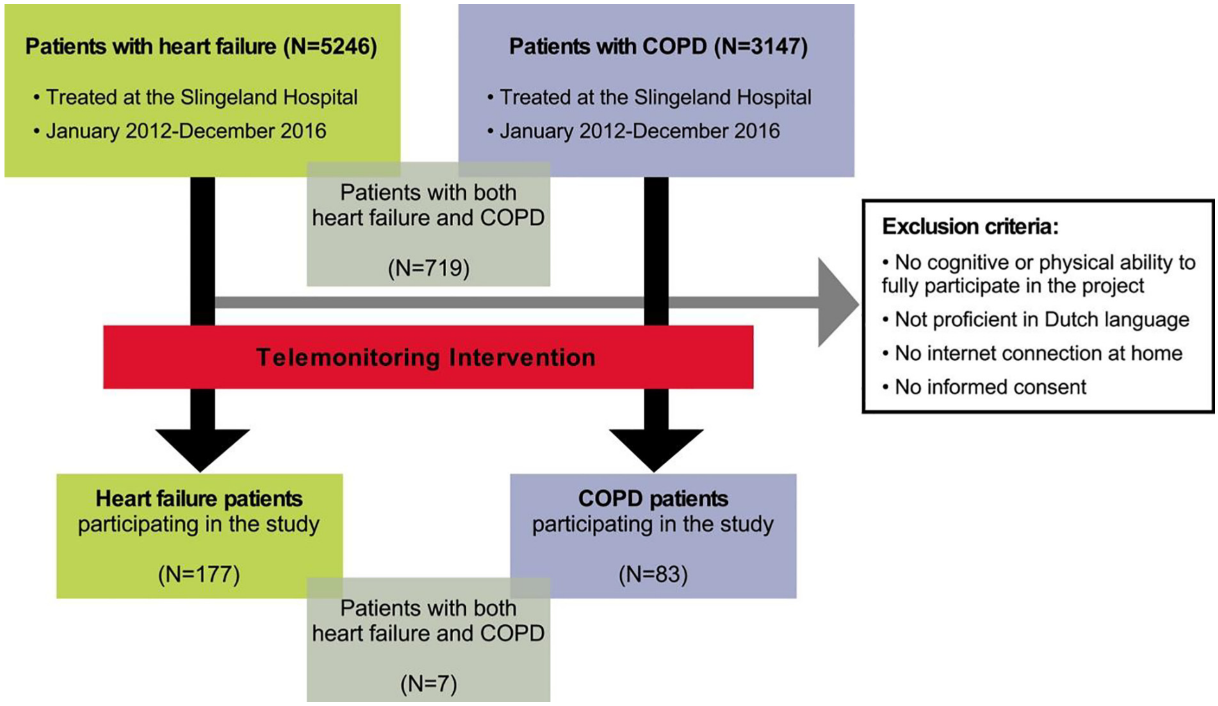

Fig. 1. Flowchart of the study population.

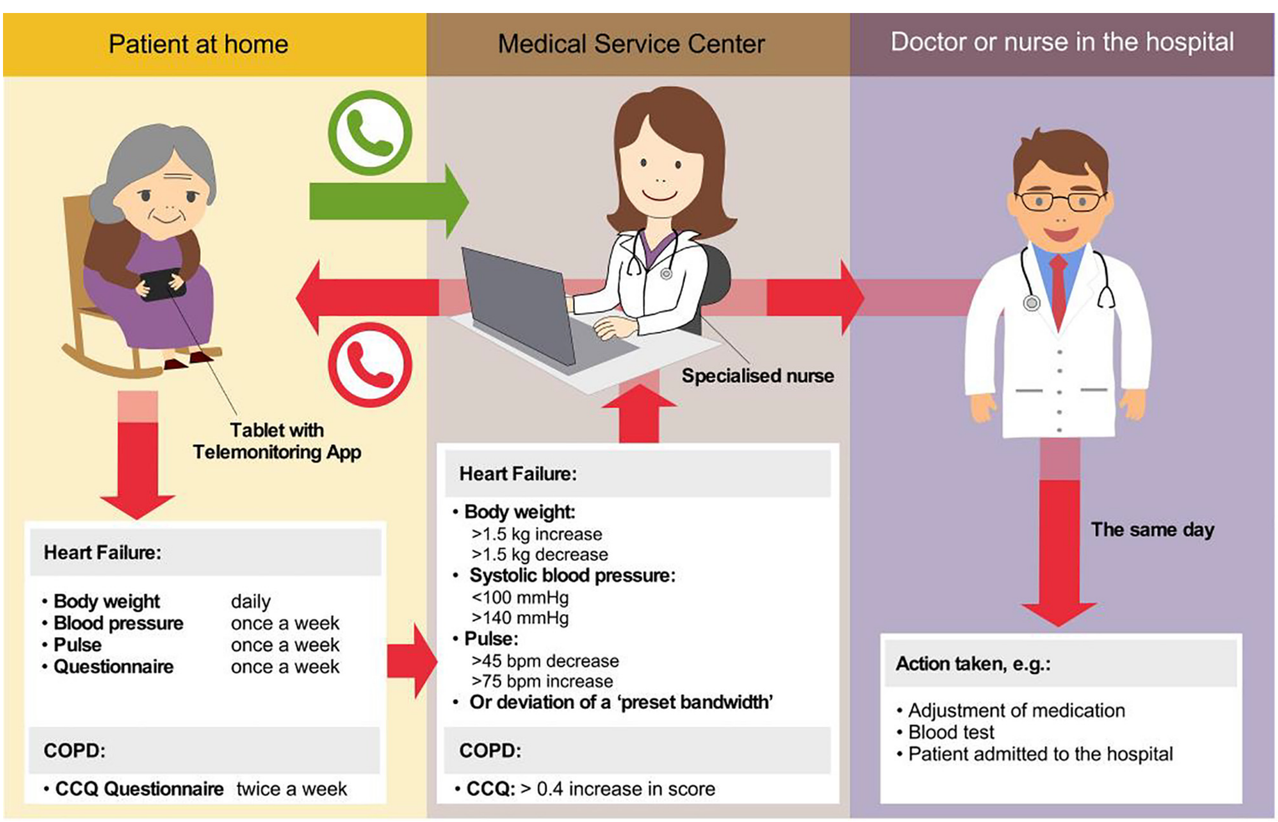

Fig. 2. Schematic representation of the telemonitoring intervention. At home registration of different measurements were sent via a specially designed application on an iPad to a Medical Service Center (MSC) for diagnostic interpretation and monitoring. In case of abnormal results, the specialized nurse at the MSC would contact, if necessary, both the patient and the doctor or specialized nurse in the hospital and action would be taken (red arrows). Patients could also contact the nurse at the MSC themselves at all times (green arrow).

would have to enter the measurements manually. For all patients, a trained nurse established a personal bandwidth for the different parameters, based on the stage and stability of the disease, and use of medication. This personal bandwidth was determined after a 'measuring week', where patients measured their parameters every day. Bandwidths could be set for both minimum and maximum absolute values as well as for the difference with the previous measurement. These bandwidths could be altered by the nurse at all times. Patients were able to see their own measurements and threshold limits over time within the application.

The integrated telemonitoring intervention for COPD consisted of twice weekly registration of symptoms via the Clinical COPD Questionnaire (CCQ). The CCQ is a simple, validated health-related quality of life questionnaire, consisting of 10 questions.[25] It is widely used worldwide and has been demonstrated to predict health status and mortality in COPD patients.[26,27] The outcome of the CCQ is an overall clinical control score ranging from 0 (very good control) to 6 (very poor control).

Home registrations were sent to a Medical Service Center (MSC; NAAST, Varsseveld) for diagnostic interpretation and monitoring (Fig. 2). Patients who failed to provide their data in time were called by the study nurse of the MSC to ensure continued compliance. Entered data was evaluated automatically based on the bandwidths set by the nurse, and the Medical Service Center was available 24/7 for patients. An alert was generated if either the personal bandwidth or the difference with a previous measurement was exceeded. Consequently, a trained nurse at the MSC contacted the patient within 4 h through a video chat call. In addition, weight and CCQ-scores were also considered abnormal when the difference with the previous measurement exceeded a preset value. A weight increase of more than 1.5 kg and 0.4 points increase in CCQ score were always, despite the preset bandwidth, considered abnormal. In case of abnormal results, the nurse at the MSC could contact a specialized nurse from either the pulmonology or cardiology department in the hospital (within office hours), or the medical specialist (outside office hours). The specialized nurse or medical specialist could further assess the situation, contact the patient, evaluate and adjust medication, and observe medication administration.

2.5. Data collection

Patient data from 1 January 2012 until 31 December 2016 was obtained from the electronic patient files from the Slingeland Hospital. Only data from patient files with diagnostic codes concerning heart failure or COPD were included. All data was pseudonymised before statistical analysis. Differences in healthcare utilization were measured by the number of hospitalizations per year related to COPD or heart failure, and the number of hospitalization days in case of hospitalization. Only hospitalizations with a duration of at least 1 day were included; thus patients who visited the Emergency Department and were discharged on the same day were not counted as a hospitalization. All patients who met our inclusion criteria were approached for enrollment in the study, including those who had a follow-up duration of $\leq$1 month. However, in case a patient enrolled the study after a recent hospitalization, the initial hospitalization was not counted as part of the pre-intervention period. Differences in total healthcare costs were compared before and after the start of the intervention and consisted of all activity based costs incurred in the hospital, including consultations, hospitalizations, blood tests, spirometry, X-rays, electrocardiography, Holter monitoring, and more. The estimation of total costs was independent of whether a patient was hospitalized or visited the Emergency Department or the outpatient clinic. For duration of follow-up before start of the intervention the time period between the first registered date per patient after January 1st, 2012, and start of the intervention was calculated. For duration of follow-up after the start of the intervention the time period between the start of the intervention and 31 December 2016, or earlier if a patient for some reason (e.g. death or no longer being able to fulfill the requirements of participation) had to quit the program, was calculated. Thus, our analyses were based on those individuals who had follow-up data available both before and after the start of the telemonitoring intervention. This way, the prepared dataset contained two data points per patient per outcome variable (i.e. number of hospitalizations, number of hospitalization days and total healthcare costs): One data point before the start of the intervention period and one data point after the start of the intervention.

2.6. Statistical analysis

Data are presented as means and confidence intervals (CIs) or medians and interquartile ranges (for non-normally distributed variables) unless otherwise specified. Patients who were diagnosed with both COPD and heart failure ($N = 7$) were included in the telemonitoring programs for both conditions and analyzed as such. To account for the repeated intra-individual measurements before and after the initiation of the telemonitoring program, we used Generalized Estimating Equation (GEE) with an independent covariance matrix.

Our primary outcome was the total number of hospital admissions, whereas our secondary outcomes were the total number of hospitalization days as well as the total healthcare costs during the follow-up period, comparing the period before and after the start of the intervention (i.e., length of follow-up before the start of the intervention, and length of follow-up during the intervention). For the analysis of the effect of the intervention on the number of hospital admissions and the number of hospital admission days, which can be conceptualized as count data, we used GEE models with a negative binomial log link-function to account for potential overdispersion. Total healthcare costs were strongly right-skewed, and therefore, were first log-transformed and subsequently analyzed using GEE models with a normal link-function. As explanatory variables we used length of follow-up (log-transformed), sex, age at baseline and telemonitoring intervention (coded as 0 or 1 for the pre- and post-intervention period, respectively). Furthermore, we performed a sensitivity analysis by including follow-up time as an offset variable, instead of an explanatory variable, to assess whether different specifications of time would affect our results. All GEE covariance estimates were based on robust estimators (i.e. Huber-White robust sandwich estimators) which provide consistent estimates even when the correlation matrix is misspecified (in contrast to generalized linear mixed effect models which are more sensitive to covariance structure misspecification). To visualize the results for each outcome variable we plotted the model predictions against follow-up time applying spline regression to depict trends over time. A p-value of less than 0.05 was considered statistically significant. All analyses were performed using SPSS version 25 (Released 2017, Armonk, NY: IBM Corp.).

3. Results

3.1. Baseline characteristics

One hundred seventy-seven patients with heart failure and 83 patients with COPD were included in the study. The characteristics of the participants with heart failure or COPD before and after the start of the telemonitoring program are displayed in Tables 1 And 2. The duration of participation differed between patients. Of the patients with heart failure, 85 patients (48.0%) were included in the telemonitoring program for at least 12 months. Fifty-four

Table 1
Patient characteristics before the intervention.

Variable	COPD (n = 83)	Heart failure (n = 177)
Age (years)[+]	Median 65.5 (IQR 60.7–71.4)	Median 70.3 (IQR 63.5–78.5)
Sex (% female)	56.6	32.8
Duration of specialist treatment (days)	Median 918.0 (IQR 623.0–1205.0)	Median 174.0 (IQR 32.0–719.0)
– Duration of follow-up ≤1 month, N (%)	3 (3.61)	46 (26.0)
– Duration of follow-up ≥1 year, N (%)	73 (88.0)	69 (39.0)

[+] At start of the telemonitoring intervention.

Table 2
Outcomes after intervention.

Variable	COPD (n = 83)	Heart failure (n = 177)
Duration of inclusion in the home telemonitoring program (days)	Median 563.0 (IQR 281.0–758.0)	Median 345.0 (IQR 142.5–628.0)
– Duration of inclusion ≤1 month N (%)	4 (4.8)	12 (6.8)
– Duration of inclusion ≥1 year N (%)	54 (65.1)	85 (48.0)
Deaths N (%)	15 (18.3)	29 (16.4)
Lost to follow-up N (%)[*]	4 (4.8)	37 (20.9)

[*] Data on the lost to follow-up reasons were not systematically collected, but included relocation to other areas within the Netherlands and revocation of the informed consent by some participants primarily due to the perceived intensity of the intervention.

patients with COPD (65.1%) were included in the telemonitoring program for at least 12 months.

In the cohort with heart failure patients, the median age was 70.3 years (IQR 63.5–78.5 years). Thirty-three percent (32.8%) of the participants was female (Table 1). The median [IQR] follow-up duration of the cardiologist before start of the telemonitoring intervention was 174.0 [32.0–719.0] days. The median duration of inclusion was 563.0 days (IQR 281.0–758.0). Twenty-nine patients (16.4%) died during the telemonitoring intervention period, while 37 patients (20.9%) were lost to follow-up for other reasons before the pre-defined end-date of the intervention.

In the cohort with COPD patients, the median [IQR] age was 65.5 [60.7–71.4] years, and 56.6% of the participants was female (Table 1). The median [IQR] follow-up by the pulmonary specialist before start of the telemonitoring intervention was 918.0 [IQR 623.0–1205.0] days. As shown in Table 2, the median [IQR] duration of inclusion in the program was 563.0 [281.0–758.0] days. Fifteen patients (18.3%) died during the telemonitoring intervention period, while 4 patients (4.8%) were lost to follow-up for other reasons before the pre-defined end-date of the intervention.

3.2. Effects of telemonitoring in patients with heart failure

In patients with heart failure, after the start of the telemonitoring intervention, the rate of hospital admission decreased by approximately 65% (incidence Rate Ration (IRR) = 0.35, 95% CI: 0.26–0.48, $p < 0.001$), Fig. 3A. The number of hospital admission days also significantly decreased in the period after the telemonitoring intervention was started (IRR = 0.35, 95% CI: 0.24–0.51, $p < 0.001$), Fig. 3B. Similarly, the total incurred costs were almost 90% lower in the period of telemonitoring as compared to the period preceding the commencement of the intervention (exp(B) = 0.1, 95% CI: 0.08–0.17, $p < 0.001$) (Fig. 3C). The rate of hospital admission, number of hospital admission days as well as total costs increased with every year of follow up, but neither age at baseline nor gender were significantly associated with any of the outcome measures (both $p \geq 0.178$) (Table 3). We also fitted a model including the Intervention × Follow-Up interaction but this did not improve model fit so it is not reported further. The effects of telemonitoring became even more pronounced in a sensitivity analysis in which we included follow-up time as an offset variable (Supplementary Table 1).

3.3. Effects of telemonitoring in patients with COPD

In patients with COPD, the telemonitoring intervention was not significantly associated with either the number of hospital admissions (IRR = 1.09, 95% CI: 0.72–1.64, $p = 0.684$) or the number of hospital admission days (IRR = 1.04, 95% CI: 0.63–1.71, $p = 0.879$) (Fig. 4A and B). However, the total healthcare costs in the period after the initiation of the telemonitoring program were significantly lower as compared to the period preceding the intervention (exp(B) = 0.46, 95% CI: 0.25–0.84, $p = 0.011$) (Fig. 4C). The effect of follow-up time on the number of admissions, the number of admission days as well as total costs was much more pronounced in patient with COPD as compared to patients with heart failure, with risk of being admitted increasing by almost 60% per year (Table 4). In parallel to the findings in patients with heart failure, neither age nor gender was significantly associated with any of the predefined outcome measures in patients with COPD (Table 4). We also fitted a model including the Intervention × Follow-Up interaction but this did not improve model fit so it is not reported further. However, the sensitivity analysis with follow-up time as the offset variable, suggested a borderline significant effect on the number of admissions, with a slightly higher number of admissions per year during the intervention period. Moreover, the effect on total costs became non-significant, although still indicating a lower amount of costs per year during the intervention period (Supplementary Table 2). Therefore, the effect of telemonitoring in COPD patients is likely to be more complex, possibly because of a strong confounding effect of time, i.e. disease progression.

4. Discussion

4.1. Principal findings of the study

We reported the results of a home telemonitoring intervention with a follow-up duration of up to three years in a group of patients with heart failure and a group of COPD patients in a before-after study design. To our knowledge, this is the first time that the effect of telemonitoring is studied conjointly in two of the most common chronic diseases with such a relatively long follow-up duration. Our most important finding is that telemonitoring can significantly decrease both the number of hospitalizations and the duration of hospitalization in patients with heart failure, but we did not observe this difference in patients with COPD. These effects remained significant after adjusting for baseline characteristics. These findings are in line with previous studies that found a positive effect of home telemonitoring in patients with heart failure,[9,28] but not in patients with COPD.[8,20,21,23]

There are several explanations why home telemonitoring may have a significant effect in heart failure patients, but not in patients with COPD. First, this could result from differences in disease characteristics, making one disease more receptive to a telemonitoring intervention than the other disease. It is known that in patients with chronic heart failure deterioration in symptoms, including weight gain, are usually present 8 to 12 days before admission to a hospital.[29,30] Rapid up-titration of diuretics or other adjustments of medication could reverse these symptoms and potentially pre-

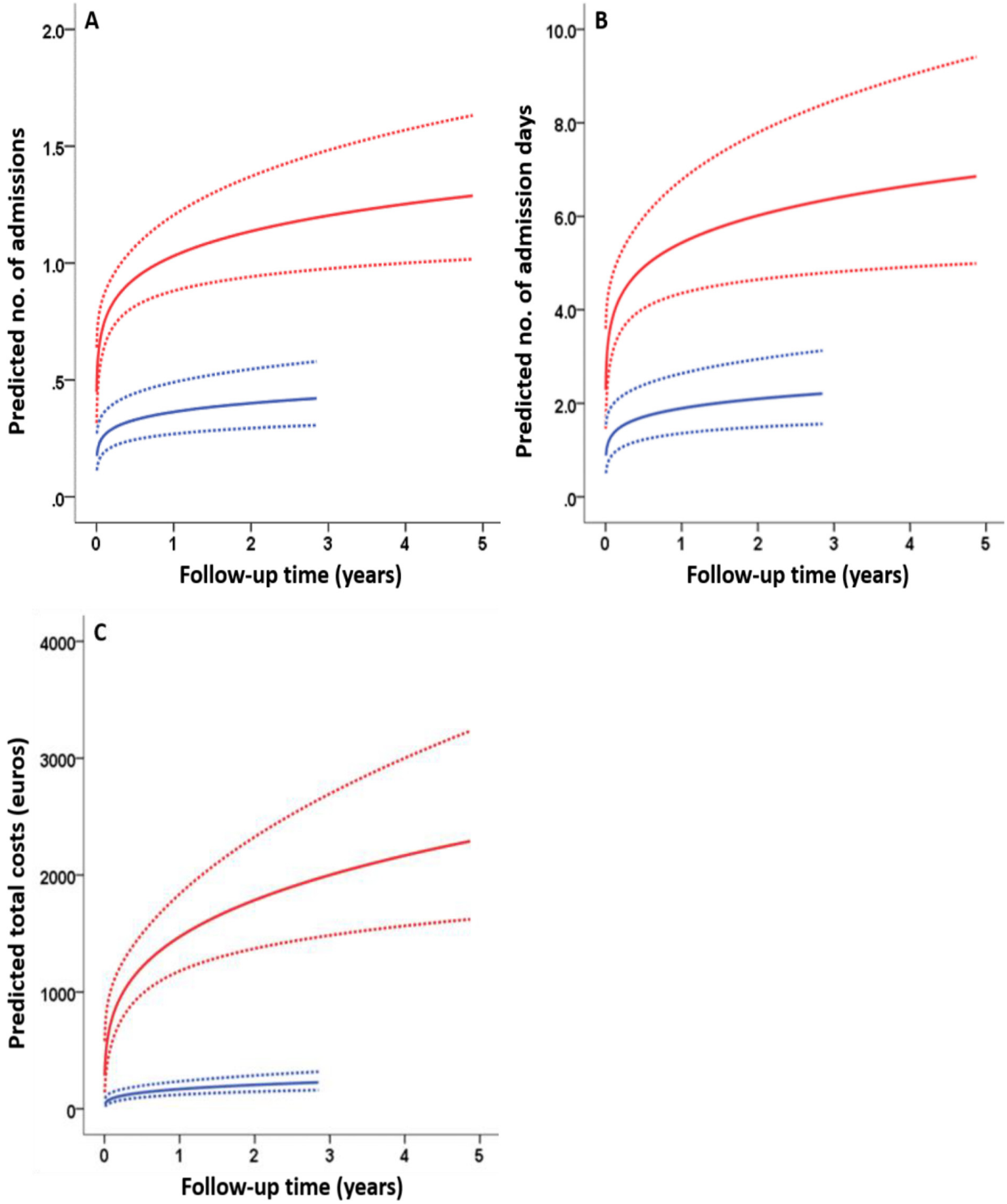

Fig. 3. Effects of telemonitoring on healthcare usage in patients with heart failure. Effects of telemonitoring on the number of hospital admissions (A), hospitalization days (B) and hospital related costs (C) before (red) and after (blue) the home telemonitoring intervention in patients with heart failure. The solid lines represent the model predicted mean values, which can be interpreted as the cumulative effect over time, with the associated 95% confidence intervals of the mean indicated by the dashed lines.

Table 3
Effect of telemonitoring on heart failure.

	No. hospital admissions		No. of admission days		Total costs	
	IRR (95% CI)	*p*-Value	IRR (95% CI)	*p*-Value	exp(B) (95% CI)	*p*-Value
Follow-up time (per year)	1.15 (1.08–1.24)	<0.001	1.15 (1.05–1.26)	0.002	1.33 (1.17–1.51)	<0.001
Age at baseline (per year)	1.01 (0.99–1.02)	0.334	1.01 (0.99–1.03)	0.282	1.00 (0.98–1.01)	0.829
Gender (female)	0.81 (0.59–1.10)	0.178	1.08 (0.72–1.62)	0.708	0.91 (0.56–1.48)	0.702
Intervention (yes/no)	0.35 (0.26–0.48)	<0.001	0.35 (0.24–0.51)	<0.001	0.11 (0.08–0.17)	<0.001

The estimates are based on the outcomes of the Generalized Estimating Equations models in which follow-up time, age at baseline, gender and intervention were included as covariates (see methods section for more details). Abbreviations: CI, confidence interval; IRR, incidence rate ratio.

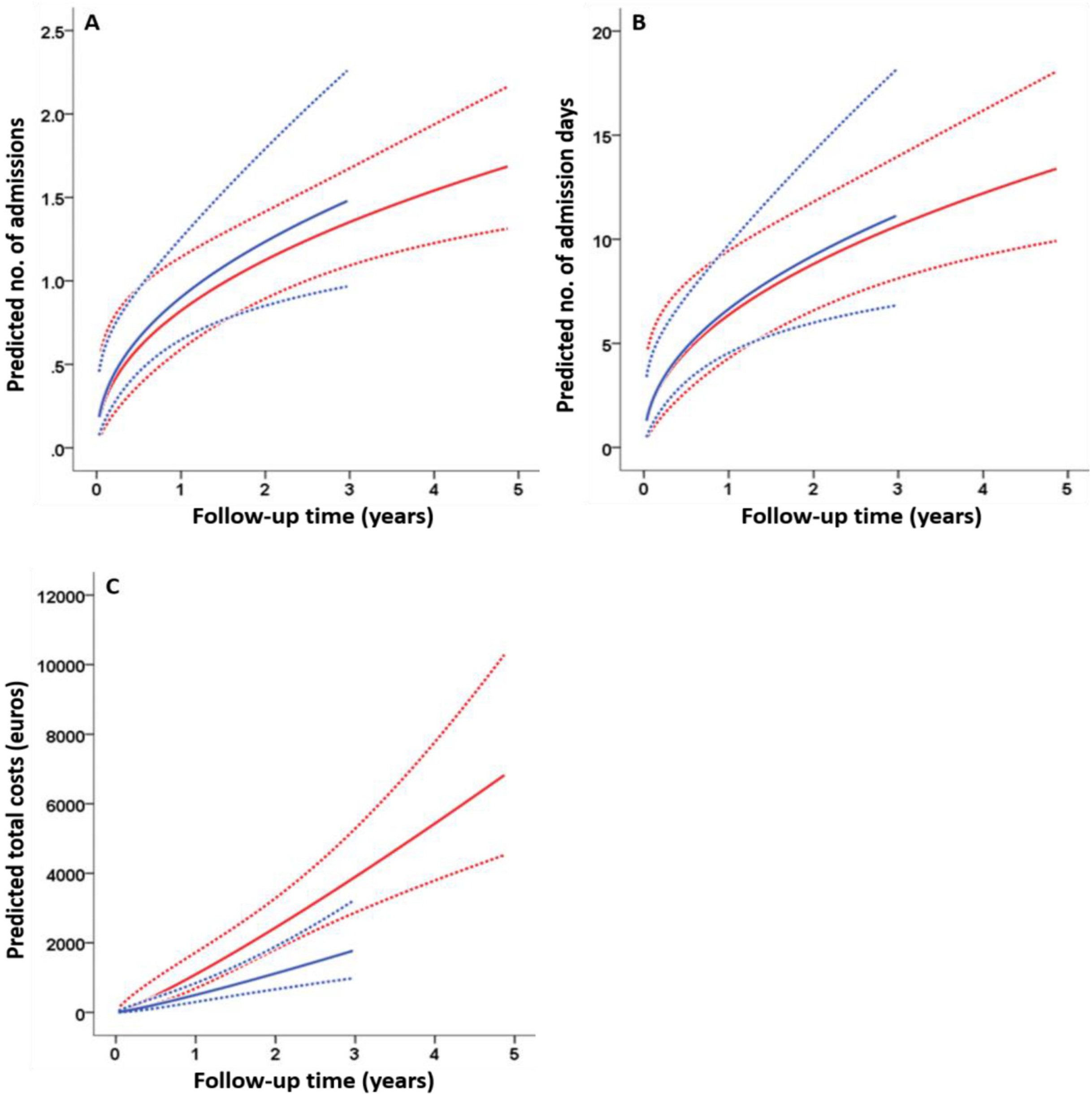

Fig. 4. Effects of telemonitoring on healthcare usage in patients with COPD. Effects of telemonitoring on the number of hospital admissions (A), hospitalization days (B) and hospital related costs (C) before (red) and after (blue) the home telemonitoring intervention in patients with COPD. The solid lines represent the model predicted mean values, which can be interpreted as the cumulative effect over time, with the associated 95% confidence intervals of the mean indicated by the dashed lines.

Table 4
Effect of telemonitoring on COPD.

	No. hospital admissions		No. of admission days		Total costs	
	IRR (95% CI)	*p*-Value	IRR (95% CI)	*p*-Value	exp(B) (95% CI)	*p*-Value
Follow-up time (per year)	1.57 (1.23–1.99)	<0.001	1.59 (1.22–2.06)	0.001	3.12 (2.15–4.73)	<0.001
Age at baseline (per year)	1.02 (0.99–1.05)	0.257	1.01 (0.99–1.04)	0.353	0.99 (0.95–1.04)	0.807
Gender (female)	1.21 (0.75–1.94)	0.433	1.31 (0.77–2.26)	0.322	1.58 (0.81–3.10)	0.179
Intervention (yes/no)	1.09 (0.72–1.64)	0.684	1.04 (0.63–1.71)	0.879	0.46 (0.25–0.84)	0.011

The estimates are based on the outcomes of the Generalized Estimating Equations models in which follow-up time, age at baseline, gender and intervention were included as covariates (see methods section for more details). Abbreviations: CI, confidence interval; IRR, incidence rate ratio.

vent hospitalization.[29] Therefore, heart failure patients may highly benefit from early detection of deterioration. Conversely, it could well be that in COPD, due to its different characteristics, there are not such clear cut predictors of an upcoming acute exacerbation as weigh gain in heart failure. Moreover, it may be that rapid adjustment of medication has less effect in preventing an exacerbation in patients with COPD compared to patients with heart failure.

Second, it might be that telemonitoring has an effect in heart failure patients, but not in COPD patients, because of the lack of sensitive and specific at home predictors of an imminent exacerbation in COPD patients.[31] Levels of CRP and (pro)calcitonin in blood of COPD patients have been found to be reliable predictors of an upcoming exacerbation, but these are not easily available at home on a regular basis. Other potential biomarkers of an impending exacerbation, such as decreases in oxygen saturation levels and increases in heart rate and respiratory rate, have not yet been investigated thoroughly in the home setting. However, interestingly a recent study found that home measurements of vital signs acquired from a pulse oximeter (pulse rate and oxygen saturation) are predictive of an impending COPD exacerbation, with oxygen saturation being the most predictive.[32] Such findings could possibly explain why some studies indeed found a positive effect of telemonitoring in COPD: these studies perhaps used better predictors, such as oxygen saturation, to detect an upcoming exacerbation.

In addition to the number of hospitalizations and duration of hospitalization, we also analyzed the effects of telemonitoring on healthcare costs. There is mixed evidence as to whether home telemonitoring can reduce total costs of care. Some studies have found that telemonitoring could reduce the total healthcare costs,[33] while others found no effect[11,34,35] or only found a reduction in healthcare costs when the costs of the intervention were excluded.[36] Interestingly, we observed a significant decrease in healthcare costs both in heart failure and in COPD patients after the telemonitoring intervention had started. The costs that we have compared before and after the intervention include all costs incurred in the hospital, including consultations, hospitalizations, blood tests, spirometry. However, the costs for the intervention could not be included in the analyses. The reason for this is that the costs of the intervention were absolute costs, whereas the costs incurred in the hospital are not absolute, but indirect costs. This is because the Dutch healthcare system is characterized by a payment system called 'Diagnosis-Treatment Combinations (DBCs)'. According to this system, the health insurance company pays a predetermined price for a package of 'care activities' that comes with a certain diagnosis. As such, hospitals themselves can determine the price of each care activity within a DBC. This price is indirectly based on real costs, is negotiable and may vary from hospital to hospital. As our analyses concerned patients from only one hospital who all received comparable 'Diagnosis-Treatment Combinations', however, this could not have affected our findings of decreased total healthcare costs.

The decrease in costs we found after the start of the intervention is spectacular and although these are not absolute costs, we believe that telemonitoring, if applied to the right target group and under the right circumstances, can lead to a significant reduction in healthcare costs. From our study it has not become clear which factors define the 'right target group' or the 'right circumstances' and this is certainly a point of attention for our follow-up studies.

Interestingly, total costs of care activities in COPD decreased despite the lack of a reduction in hospitalizations and hospitalization duration. From our dataset it was impossible to further analyze why the total healthcare costs declined in the COPD group. We hypothesize that since the start of the telemonitoring intervention COPD patients needed less consultations, blood tests, spirometry, X-rays, sputum cultures and other investigations. These findings are in line with findings of the 'Whole Systems Demonstrator telehealth questionnaire study' that found a slight decrease in total costs for health and social care of a 12 months telemonitoring intervention when the costs of the intervention were excluded.[36] We are planning to further investigate the cost effectiveness of telemonitoring, especially the observed decrease in costs in COPD, more thoroughly in a future research project. Future studies should also focus on the differences in patient 'types' (e.g., 'active', 'passive'), individual disease progression trajectories and the consequences in responsiveness to home telemonitoring and patient outcomes.

4.2. Strengths and weaknesses of the study

One of the most important strengths of our study is the relatively long follow-up duration of up to three years. In addition, the patients turned out to be very motivated to continue taking part in the study and they consistently continued to send their data through the app on a daily and weekly basis. The relatively high attrition rate that we found is remarkable because attrition is often a problem in such studies.[37] Another strength of our study is the integration of the program into the usual care. This blended care is important, because such programs often do not run well due to the lack of organizational structure.

However, as we used a pre-post research design, we lacked a parallel control group. Therefore, the results of this study have to be interpreted with caution. The lack of a control group makes it more difficult to attribute observed changes to the intervention. One of the effects that particularly could play a role in such a study design, is the so called Hawthorne-effect, an often positive effect of an intervention that results solely from the fact of participating in a study because of the feeling of being observed. However, as both the heart failure and COPD group consisted of a relatively large number of participants, who were followed for several years, it is likely that similar results would have been found as in a matched-control study design as the Hawthorne-effect is expected to disappear within a few months.

Further, it is important to note that due to the restrictive selection criteria, only a relatively small proportion of the patients that were treated for COPD or heart failure at the Slingeland hospital were able to participate in the study. Although it is possible that this subset of patients may not be representative of the entire group of patients seen in this regional hospital, this does not affect our finding with regard to the effects of the eHealth intervention per se. This is because we applied a pre-post-intervention design which enabled us to compare the effect of the intervention within every individual separately. Only patients who were willing to use telemonitoring were included. These patients may have been more motivated to change their behavior, which might have affected our results regarding hospitalizations and costs. However, if we would have also conducted the study on patients who were not motivated to participate or who were unable to participate, that would have been a far cry from the daily practice, especially with regard to these kinds of interventions that require high patient compliance and commitment. Just like any drug therapy, eHealth will not be suitable for everyone and will not be effective for everyone. Therefore, our results are not generalisable to all heart failure and COPD patients. Further studies are needed to find out which characteristics make a patient suitable for participation and in whom to expect a beneficial effect from eHealth monitoring.

Moreover, approximately 21% of the patients were lost to follow-up. Among the reasons for disenrollment was the perception that the intervention was too intensive. It could be that patients who disenrolled, often had a high burden of disease and thus would have had high costs if they had remained in the analysis.

Finally, the health care system and overall healthcare costs differ from country to country. Further studies are necessary to investigate whether the telemonitoring intervention as performed in the Slingeland hospital is also cost-effective in other hospitals and in other countries.

4.3. Conclusions

Our results suggest that home telemonitoring significantly decreases the number of hospitalizations as well as the total days of hospitalization in patients with heart failure, but not in patients with COPD. Nevertheless, we observed a strong and significant decrease in total healthcare costs in both heart failure and COPD after the initiation of the home telemonitoring intervention. The mechanism behind these effects of home telemonitoring is not yet clear. It is likely that home telemonitoring helps patients to manage their conditions better and leads to earlier detection of deterioration, thereby reducing the incidence of acute exacerbations that necessitate emergency admission. Moreover, telemonitoring could change people's perception of when they need to seek additional support, as well as professionals' decisions about whether to refer or admit patients. Further research, preferably multi-center randomized controlled studies in which different at home measurements are compared (including body weight, heart rate, blood pressure, oxygen saturation, breathing rate and questionnaires) are needed to unravel the exact mechanisms by which home telemonitoring can lead to reductions in hospital care and healthcare related costs.

Conflicts of interest

We have no conflicts of interest.

CRediT authorship contribution statement

Jorien M.M. van der Burg: Conceptualization, Data curation, Formal analysis, Methodology, Writing - original draft, Writing - review & editing. **N. Ahmad Aziz:** Conceptualization, Data curation, Formal analysis, Validation, Writing - review & editing. **Maurits C. Kaptein:** Formal analysis, Validation, Writing - review & editing. **Martine J.M. Breteler:** Software, Methodology, Writing - review & editing. **Joris H. Janssen:** Software, Methodology, Writing - review & editing. **Lisa van Vliet:** Investigation, Writing - original draft. **Daniel Winkeler:** Investigation, Resources, Methodology, Project administration, Writing - review & editing. **Anneke van Anken:** Investigation, Resources, Writing - review & editing. **Marise J. Kasteleyn:** Conceptualization, Visualization, Writing - review & editing. **Niels H. Chavannes:** Supervision, Project administration, Visualization, Writing - review & editing.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ceh.2020.05.001.

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