Patients on Home Telehealth Monitoring have more Days Alive and Out of Hospital

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Abstract

Although randomised controlled studies have demonstrated that home tele monitoring might improve outcomes for patients being discharged from hospital following an admission for heart failure, it is not known whether the effect is seen in patients encountered in daily practice. We investigated the impact of Home Telehealth Monitoring (HTM) using a dedicated heart failure database in Hull, UK. We used propensity matching to compare outcomes between patients receiving HTM and those not. After matching there were 202 patients (26% Female, 68.3 ± 12.5 years). The primary endpoint was mortality at 1 year. Usual care patients had a greater 1 year mortality (HR: 3.20, 95% CI: 1.40 – 7.28, P = 0.006) and a greater risk of death at 3 years (HR: 1.75, 95% CI: 1.05– 2.90, P = 0.03). There was no difference between the groups in the composite endpoint of death or hospitalisation within one year (HR: 0.74, 95% CI: 0.51– 1.07, P = 0.11). Patients using HTM spent 96% of the available days alive and out of hospital compared with 87% of the usual care group. HTM thus improves outcomes in real-world patients discharged from hospital following an admission for heart failure.

1 Introduction

Chronic heart failure (CHF) costs the UK economy approximately £563 million per year [1]. The greatest part of the cost is due to hospitalisation. After an admission patients with CHF have a high risk a readmission with 30% of patients who are discharged following an admission for heart failure having at least one hospital readmission within 90 days of discharge [2] rising to 50% within 6 months [3], [4]. CHF affects more than 900,000 people in the UK and accounts for 1 million in-patient bed days per year [5]. CHF affects 5 million people in the USA [6] and 10 million people in the EU [3].

One of the challenges facing care providers is that of providing cost-effective services while maintain high quality of care that is compliant with healthcare guidelines. There is growing interest in Home Telehealth Monitoring (HTM) for patients with CHF. With HTM, easy-to-use devices are provided to the patients. The devices measure simple physiological variables such as heart and rhythm, blood pressure and weight which are transmitted to a central data server. Clinicians access the data in order to assess the well-being of the patients and to make interventions that might prevent a readmission (Figure 1).

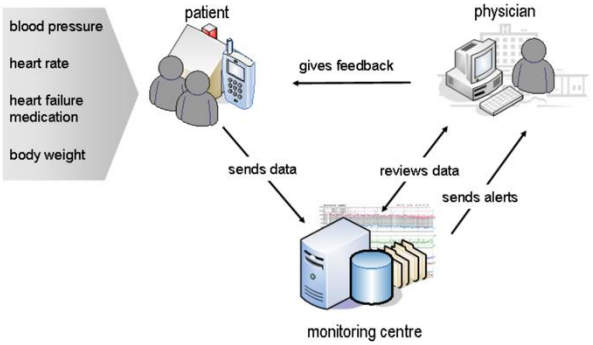

Figure 1: Overview of HTM [7]

A number of studies has reported the performance of HTM. Some have reported reductions in mortality with HTM [8]–[12] but others have not [13]–[16]. Similar results have been reported when considering hospitalisation with some showing a reduction [8], [10], [11], [17]–[21] and others not [13]–[16], [22]. A systematic Cochrane review concluded that structured telephone support alongside HTM improved patient outcomes [23].

A key issue with the comparison of different HTM studies is that although the devices are standardised there are differences that might affect compliance and the quality of data. The approaches studied have included the use of an Interactive Voice Recording (IVR) system were a patient rings a dedicated telephone number and answers a series of automated questions commonly using a touch pad or voice recognition. An alternative method is the use of a Structured Telephone Call (STC) with an experienced heart failure nurse [8], [20], [24]. A more complex version of the STC was attempted through the use of a video conference system [25]. Other trials make use of devices connected to the telephone system to allow the automatic transmission of the measurements to the care provider [16], [26]. In some cases commercially developed equipment has been used such as Honeywell HomMed [27],

[28], Alere DayLink [6], [9] and Philips Motiva [29]. A more recent example used a Personal Data Assistant (PDA) which transmitted measurements via a mobile phone [15]. The trials also differed the frequency with which measurements were made. In some cases STCs were made daily [18] with other trials using a range of different time intervals (weekly and monthly) [14]. Data monitoring also varies considerably. With one system the data is monitored by HF and clinical staff using a traffic light approach with red represented data received outside the predefined bounds and yellow highlighting missing data [28]. In other examples automatic alerts are raised when the data is outside of a predefined range [10], [13]. An example of alert criteria is shown in Table 1.

Measurement	Alert Criteria
Resting heart rate	< 50 beats/min Or > 80 beats/min
Systolic blood pressure	< 90 mm Hg Or > 140 mm Hg
Weight Change	Change > 2kg

Table 1: Alert Criteria [10], [12]

A further problem is that all clinical studies recruit only a subset of all possible patients who meet the entry criteria for a clinical trial. It is not at all clear whether the results can be extrapolated to 'real world' patients encountered in day-to-day practice.

In this paper we evaluate the impact of impact of HTM on patients with CHF in the Hull and East Riding of Yorkshire who have visited the community heart failure service.

2 Methodology

We used the Hull-Lifelab dataset which is a longitudinal study patients with CHF [30]. It has over 6,000 unique patient records at baseline and data from follow ups since 2000. The data includes demographics, laboratory blood test results, echocardiogram results, features from clinical examination and quality of life. The data are collected from all patients attending the Hull and East Yorkshire community heart failure service. We used propensity matching to compare patients who received HTM with those who received usual care.

Categorical data are presented as percentages and continuous data as mean ± standard deviation (SD). Cox proportional hazard analyses were used to assess prognostic associations. The hazard ratio (HR) with 95% confidence intervals (CI) and P values from the likelihood-ratio test are given. Hazard ratios for continuous variables apply per unit of the analysed variable. Kaplan-Meier cumulative survival plots were constructed to illustrate the results. Days Alive and Out of Hospital (DAOH) approach were also calculated [31].

2.1 Home Telehealth Monitoring

HTM is routinely offered to all patients leaving hospital following an admission for heart failure in the Hull and East Riding of Yorkshire [32]. The patients who agree are given a Philips Motiva system which transmits the data to the clinical team where it is reviewed daily. The Motiva system also offers educational support on a range of topics including, but not limited to, nutrition, physical exercise, stress and depression [33]. These are presented to the patients as scheduled educational videos via a secure broadband home TV channel [32].

2.2 Propensity Matching

The HTM dataset contains daily records for heart rate, blood pressure and weight for 129 patients. The characteristics of the patients receiving HTM are statistically different from the patients who received usual care (Table 2). To reduce the differences between the two groups and match the patients we used a propensity score matching method with the intention of estimating the likelihood of receiving treatment based on covariate scores [34,35]. The probability of a patient receiving treatment $p(X)$ can be estimated based on the explanatory variables x which belong to the patient X and the binary outcome y which belongs to $\{0, 1\}$ as shown in Eq. 1.

$$p(X) = f(y \in \{0,1\} | x \in X) \quad (1)$$

A logistic regression model was used to determine the probability of a patient $p(X)$ receiving HTM. This is linked to linear model as shown in Eq. 2

$$X\beta = \beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n + \varepsilon \quad (2)$$

where $\beta_0, \beta_1 \ldots \beta_k$ are the estimated coefficients, $x_1 \ldots x_k$ are the explanatory variables with ε the error. A probabilistic value is determined through the logistic function as shown in Eq. 3.

$$p(y = 1 \,|\, X) = (1 + exp(-X\beta))^{-1} \quad (3)$$

The explanatory variables we used for the logistic regression model was age, gender and weight together with laboratory variables (sodium (mmol/L), urea (mmol/L) and amino-terminal pro-B-type natriuretic peptide (NT-proBNP) (ng/L)) and medication (furosemide (mg) and betablocker use). Combining Eq. 2 and Eq. 3 we get:

$$p(x) = \frac{1}{1 - e^{(\beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n)}} \quad (4)$$

Pairs of patients are matched between the two groups based on the probability of receiving HTM. This was achieved through matching the probability scores to their nearest neighbour within a fixed calliper width. A calliper width of 0.02 was selected as it is shown to be effective in estimating treatment effects [34]. If no match was found then the patients were not included in the analysis. From 129 HTM patients, 101 HTM patients were matched with 101 receiving usual care. Table 2 shows the comparison between the matched patients. The

	Before Matching			After Matching		
Variable	**Usual Care**	**HTM**	**P**	**Usual Care**	**HTM**	**P**
Number of Patients	3085	129	NA	101	101	NA
Age	72.4 (11.2)	67.6 (11.4)	< 0.001	68.9 (12.9)	67.8 (12.2)	0.56
Female	40.70%	20.90%	< 0.001	28.70%	22.80%	0.42
ACE	54.60%	78.30%	< 0.001	71.30%	78.20%	0.33
ARB	15.40%	17%	0.759	11.90%	16.80%	0.42
Betablocker	57.30%	79.20%	< 0.001	82.20%	79.20%	0.72
Digoxin	15%	30.20%	< 0.001	24.80%	28.70%	0.63
Diuretic	67%	97.20%	< 0.001	96%	97%	1.00
Calcium Channel Blocker	3%	0%	< 0.001	2%	0%	<0.001
Furosemide (mg)	34.9 (42.3)	78.1 (52.5)	< 0.001	78.8 (48.8)	74.9 (48.2)	0.56
Warfarin	23.10%	36.80%	0.002	38.60%	35.60%	0.77
Systolic BP (mmHg)	139.5 (25)	126.2 (23.5)	< 0.001	127.4 (25.3)	126.4 (23.6)	0.78
Diastolic BP (mmHg)	79.1 (13.9)	74.7 (14)	0.002	76.6 (14.5)	74.9 (13.7)	0.39
Weight (kg)	82.1 (20.3)	82.6 (20.6)	0.808	81.3 (23.1)	82.1 (21.6)	0.80
BMI	29.7 (6.4)	29 (7.8)	0.398	28.9 (7.5)	29.1 (7.9)	0.87
NYHA Exam >= 3	31.70%	40.40%	0.077	39.60%	39.60%	1.00
NT-proBNP (ng/L)	1977.3 (3844.2)	3115 (5913.7)	0.077	4015.9 (5931.5)	3163.7 (6207.5)	0.39
Calcium (mmol/L)	2.3 (0.1)	2.3 (0.1)	0.664	2.3 (0.1)	2.3 (0.1)	0.38
Cholesterol (mmol/L)	4.5 (1.3)	4.4 (1.3)	0.592	4.6 (1.2)	4.4 (1.3)	0.46
Creatinine (µmol/L)	105.7 (54.8)	125.5 (63.5)	0.003	126.9 (68.5)	125.2 (65)	0.87
Urea (mmol/L)	7.8 (4.9)	9.8 (7.8)	0.015	10.3 (6.9)	9.8 (8)	0.64
Sodium (mmol/L)	138 (3.2)	136.7 (3.6)	< 0.001	137 (3.9)	136.8 (3.7)	0.76
Haemoglobin (gd/L)	13.3 (1.8)	13 (1.7)	0.106	13.1 (1.5)	13 (1.7)	0.59
Bilirubin (µmol/L)	15 (6.3)	15.8 (8.5)	0.372	15.9 (5.9)	15 (7.2)	0.34
Potassium (mmol/L)	4.4 (1.5)	4.3 (0.5)	0.339	4.5 (0.6)	4.3 (0.5)	0.06
Angina	8.10%	11.70%	0.348	7.80%	10%	0.86
Diabetic	29.60%	28.60%	0.948	30.30%	27.10%	0.82
MI	11.80%	29.90%	< 0.001	5.20%	27.10%	0.00
CABG	6%	16.90%	< 0.001	9.10%	14.30%	0.47
History of Hypertension	36.20%	24.70%	0.050	29.90%	25.70%	0.71

Table 2: Categorical and Continuous Variables Before and After Propensity Matching (Abbreviations: Angiotensin converting enzyme (ACE) inhibitors, Angiotensin II Receptor Blockers (ARB), Body Mass Index (BMI), New York Heart Association (NYHA), N-terminal pro b-type natriuretic peptide (NT-proBNP), myocardial infarction (MI) and coronary artery bypass graft (CABG))

matching process results in two well-matched groups with no significant differences between them in non-matched variables.

2.3 Evaluation Methods

We used a range of methods to assess the effectiveness of HTM. Mortality counts were compared using a chi square test of independence which is used to test if there is any correlation between the two patient groups. Survival was compared using time to first event analysis using a Kaplan Meier survival estimate and the Cox proportional hazard test. Because these methods can only detect first events we use a repeat analysis in the form of DAOH.

Chi Square Test of Independence

The chi squared (χ^2) test of independence is used to determine if two or more categorical variables are independent of each other. It is expected that if two variables are independent the

chi squared value will be zero as no correlation exists between them. Initially the expected factors are determined as $E_{r,c}$ in Eq. 5 where r and c are factors, n_r is the frequency for a single factor and n_c is the frequency for all other factors.

$$E_{r,c} = \frac{(n_r n_c)}{n} \quad (5)$$

The χ^2 value is determined as shown in Eq. 6 where $O_{r,c}$ is the observed factors.

$$\chi^2 = \sum \frac{(O_{r,c} - E_{r,c})^2}{E_{r,c}} \quad (6)$$

Kaplan Meier Survival Estimates

Kaplan Meier survival analysis is often used in analyse of data collected from clinical trials [35] as they are clear and easy to interpret [36]. The technique can be applied to any time-to-first-event analysis providing the data contains a binary value to represent the event occurring and a continuous variable representing time such as minutes, hours, days, months, years, etc. The method works by determining the proportion of events that have been observed at a given point in time, t_i. Thus if n_i represents the number of patients at risk and d_i represents the number of events at the current time then the survival estimate is given by:

$$\hat{S}(t) = \prod_{t_i<t} \left(\frac{n_i - d_i}{n_i}\right) \quad (7)$$

This results in a series of vectors which can be used to show the proportion of events which occurred at a given time index. An example of this can be seen in Figure 2.

Cox Proportional Hazard Model

The Cox proportional hazard model is a statistical method that can be used to explore the associations of covariates with time-to-event data. The survival model developed by the Kaplan Meier approach is used as the inputs for the Cox proportional hazard model. Analysis is performed to find the relationship between selected covariates and the outcome over time, this is represented as λ_0 to describe the hazard function. This can be expressed as shown in Eq. 8 when given a vector of covariates $x = (x_1, x_2, \dots, x_n)'$, the proportional risk at time t and with the regression coefficients represented as $\beta = (\beta_1, \beta_2, \dots, \beta_n)$.

$$\lambda(t|x) = \lambda_0(t)^{\exp(x'\beta)} \quad (8)$$

Days Alive and Out of Hospital

DAOH is determined as shown in Eq. 9 where n represents the number of patients, t^{alive} represents the time a patient is alive and t^{hosp} represents the amount of time the patient is in hospital.

$$DAOH = \sum_{i=n}^{n} t_i^{alive} - t_i^{hosp} \quad (9)$$

This can then extended to determine %DOAH as shown in Eq. 10 where t^{max} is the maximum possible time alive and out of hospital.

$$\%DAOH = \sum_{i=n}^{n} \frac{t_i^{alive} - t_i^{hosp}}{t_i^{max}} \quad (10)$$

3 Results

Before propensity matching the HTM cohort had a greater number of patients with more severe CHF. This is evident with a high proportion of patients identified as New York Heart Association (NYHA) class ≥ 3, higher ranges of NT-proBNP, lower blood pressure and higher levels of medication. After propensity matching the groups were statistically similar (Table 2).

Table 3 shows 28 patients deaths within the first year following an admission, 20 patients from the usual care cohort and 8 from the HTM cohort (p = 0.0251). The HTM cohort had statistically significantly fewer deaths within the first year.

	Alive	**Dead**	**Total**
HTM	93	8	101
Usual Care	81	20	101
Total	174	28	202

Table 3: One Year Mortality (x^2 p = 0.0251)

The usual care group had a greater likelihood of dying within the first year (HR: 3.20, 95% CI: 1.40 – 7.28, p = 0.006). The usual care group also had a greater likelihood of dying within three years (HR: 1.75, 95% CI: 1.05– 2.90, p = 0.032).

Figure 2 shows the Kaplan Meier curves for survival of the two groups showing better survival rates for the HTM group (Log rank test p = 0.003).

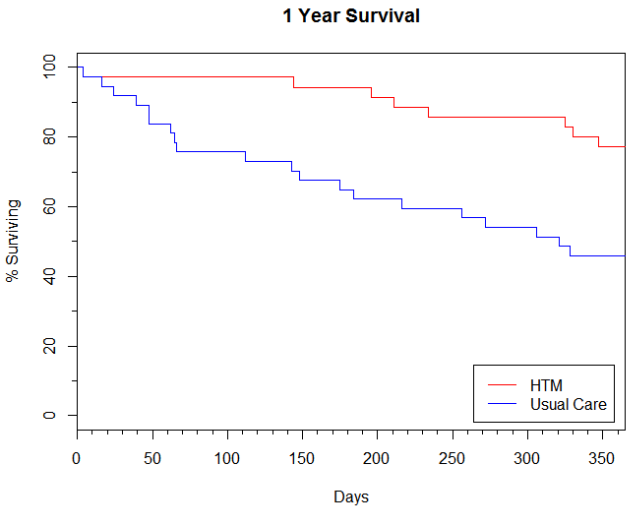

Figure 2: One Year Kaplan Meier Survival Estimates

Despite the effect of HTM on survival there was no difference between the two groups on the secondary endpoint of time to

death or hospitalisation (Figure 3) (HR: 0.74, 95% CI: 0.51–1.07, p = 0.11).

Patients receiving HTM had a greater number of DAOH during the first year (Tables 4 and 5). The HTM group stayed alive and out of hospital for 96% of the maximum possible number of days compared with 87% of the possible maximum in the usual care group. The patients receiving HTM had an average of 32.4 more DAOH than the usual care group (95% CI: 10.1 – 54.7 days, p = 0.005).

	DAOH	%DAOH
HTM	35,385.3	96%
Usual care	32,112.4	87%

Table 4: Days Alive and Out of Hospital (DAOH)

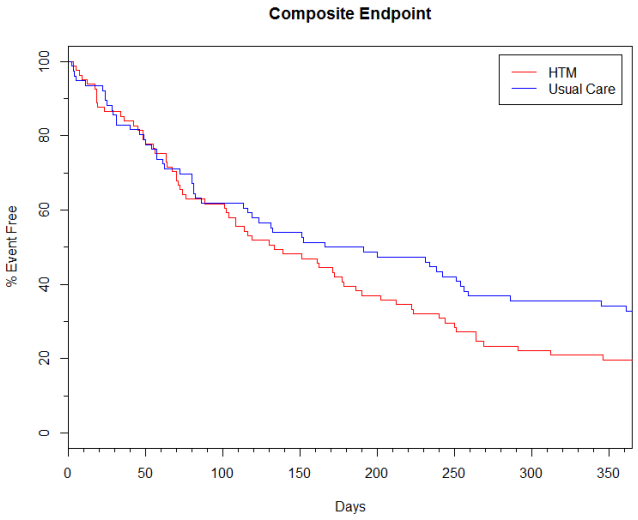

Figure 3: Time to first event of death or hosptalisation

	HTM	Usual care
Mean	350.3	317.9
SD	49.5	102.0
95 % CI	340.6 – 360.1	297.7 – 338.1
Median	365	365
IQR	±2.8	±10.5

Table 5: DAOH - Mean, Standard Deviation, Median and IQR

4 Conclusion

We have found that patients who receive HTM following an admission to hospital with heart failure have a marked improvement in survival and an increase in the number of days alive and out of hospital compared to with usual care.

One of the explanations for this improvement could be that patients are better informed of their condition. Patients who feel relatively well and take care of themselves gain little benefit from HTM [22]. In some trials it was also noted that HTM was used to reinforce educational points [20] and even provide educational prompts [13]. However further work is needed to consider the wider reasons for the reduction in mortality and the difference in DAOH.

One of the limitations of time-to-first-event analysis is that it does not account for subsequent events. The Kaplan Meier estimates show that whilst HTM is associated with fewer deaths the composite endpoint of death plus hospitalisation is not affected, suggesting a higher number of hospitalisation in the HTM group. We found that DAOH and %DAOH showed another aspect of the potential benefits of HTM compared with time-to-first-event analysis.

The strength of this work is that we have used observational data from patients seen through routine clinical practice. The use of the propensity score technique allowed for a fair comparison between patients receiving HTM and patients receiving usual care as if they are treated in a randomised clinical trial with strict inclusion criteria.

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