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TELEMONITORING AFTER DISCHARGE FROM HOSPITAL WITH HEART FAILURE - COST-EFFECTIVENESS MODELLING OF ALTERNATIVE SERVICE DESIGNS

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ABSTRACT

OBJECTIVES: To estimate the cost-effectiveness of remote monitoring strategies versus usual care for adults recently discharged after a heart failure (HF) exacerbation.

DESIGN: Decision analysis modelling of cost-effectiveness using secondary data sources.

SETTING: Acute hospitals in the United Kingdom.

PATIENTS: Patients recently discharged (within 28 days) after a heart failure (HF) exacerbation

INTERVENTIONS: Structured telephone support (STS) via human to machine (STS HM) interface, b) STS via human to human (STS HH) contact, and c) home telemonitoring (TM), compared against d) usual care.

MAIN OUTCOME MEASURES: The incremental cost per quality-adjusted life year (QALY) gained by each strategy compared to the next most effective alternative and the probability of each strategy being cost-effective at varying willingness to pay per QALY gained.

RESULTS: TM was the most cost-effective strategy in the scenario using these base case costs. Compared with usual care, TM had an estimated incremental cost effectiveness ratio (ICER) of £9,552/QALY, whereas STS HH had an ICER of £63,240/QALY against TM. STS HM was dominated by usual care. Threshold analysis suggested that the monthly cost of TM has to be higher than £390 to have an ICER greater than £20,000/QALY against STS HH. Scenario analyses performed using higher costs of usual care, higher costs of STS HH and lower costs of TM do not substantially change the conclusions.

CONCLUSIONS: Cost-effectiveness analyses suggest TM was an optimal strategy in most scenarios, but there is considerable uncertainty in relation to clear descriptions of the interventions and robust estimation of costs.

BACKGROUND

Heart failure (HF) is associated with high levels of morbidity and mortality, with the highest risk immediately after discharge from hospital.[1] 20-30% of patients are readmitted within 30 days, rising to 50% at six months.[2] Patients who are discharged have around 28% risk of mortality within the first year after HF discharge.[3] Strategies to slow disease progression are needed for at-risk patients, to improve the prognosis, even among those receiving optimal pharmaceutical therapy.[4]

Remote monitoring (RM) of indicators of deterioration (e.g. weight, arrhythmia, blood pressure, intrathoracic impedance, heart rates during rest and exertion, and symptom control) can facilitate early detection of clinically significant changes and thus earlier intervention to restabilise the syndrome, prevent emergency admissions, and avoid complications.[5] RM can be broadly classified into telemonitoring (TM), in which physiological data are electronically transmitted to a healthcare team, and structured telephone support (STS), that is, the use of phone calls, usually by specialist nurses, to deliver self-care support and/or management.[6,7] For STS, support can be provided by human-to-human contact (HH), or via a human-to-machine interface (HM); that is, STS with an interactive response system (e.g. a voice-interactive system). For TM, support can be provided during office hours only or 24 hours per day, seven days per week (24/7), though few studies have used the latter approach.

The cost-effectiveness of a RM strategy can be estimated by comparing the outcomes and costs associated with the strategy to the next most effective alternative. If these outcomes are estimated as quality-adjusted life years (QALYs) then the incremental cost-effectiveness ratio (ICER), or cost per QALY gained, can be calculated and compared to alternative uses of health care funding. In the United Kingdom (UK), NICE typically recommends in favour of funding interventions with an ICER below thresholds of £20,000/QALY, requires considerable clinical benefit to recommend funding interventions between £20,000 and £30,000/QALY, and recommends against funding interventions with an ICER above these thresholds. The aim of this paper is to estimate the incremental cost per QALY of RM strategies compared with usual care, so as to determine which RM strategy should be recommended according to typical NICE thresholds for cost-effectiveness.

METHODS

Model scope

A Markov model was developed using MS Excel software (Microsoft Corporation) to estimate the cost-effectiveness of remote monitoring (RM) interventions with usual care for patients discharged in the past 28 days with a HF-related hospitalisation, measured as the incremental cost per QALY gained by each strategy compared with the next most effective alternative on the cost-effectiveness frontier. Cost-effectiveness results are estimated as mean values of 10,000 probabilistic sensitivity analysis (PSA) runs, with each PSA run using different estimates for the risks, hazard ratios, costs and utilities sampled from probability distributions representing uncertainty in the parameter estimates. Additionally, the probability that each strategy would be the most cost-effective was calculated at different thresholds for willingness to pay (WTP) for health gain. Cost-effectiveness acceptability curves were constructed by plotting the probability of each strategy being cost-effective against WTP threshold.

The following strategies post discharge interventions were tested in the model:

a) Usual care
b) STS HH (structured telephone support with human-to-human contact)
c) STS HM (structured telephone support with human-to-machine interface) and
d) TM (i.e. telemonitoring with transmitted data reviewed by medical staff or medical support provided during office hours)

The clinical effectiveness parameters of these three RM strategies were estimated from a network meta-analysis of the available evidence,[8] and costs were estimated using 'bottom up' costing methods. It was assumed that the interventions were provided for the six months following discharge from the hospital, as the majority of the RM trials included in the network meta-analysis used a six month follow-up duration.[8] At the end of six months all patients were assumed to receive usual care as per the NICE Clinical Guidelines for the Management of Adults with Chronic Heart Failure,[9] irrespective of whether they received intervention or post discharge usual care during the treatment period.

Model structure

In the Markov model, two different states were considered:

(a) Alive at home
(b) Dead

The Markov model used a monthly cycle length with half-cycle correction and assigned each patient with a monthly probability of death based on the time since discharge and the type of treatment. In each period, the patients that were alive were under the risk of an average number of monthly re-hospitalisations i.e. readmissions to a hospital for HF or other causes. Each patient then accrued lifetime QALYs and health care costs according to their hospitalisation and treatment status. The model used a 30 year (patient lifetime) horizon although the impact of each intervention was for the first six months after an initial discharge. Both the costs and QALYs were discounted at an annual discount rate of 3.5% and the economic perspective of the model was that of NHS in England and Wales. Repeat interventions after repeat hospitalisations were not considered in this model.

Baseline mortality and hospitalisation

The baseline monthly probabilities of death were estimated from the Candesartan in Heart failure: Assessment of Reduction in Mortality and morbidity (CHARM) study,[10] which included 7572 patients followed up for 38 months, as it assessed the influence of non-fatal hospitalisation for heart failure on subsequent mortality. The data from the CHARM study[10] showed that the mortality risk was highest immediately after hospital discharge and then decreased over time, as shown in Table 1.

Table 1: Monthly mortality probability vs. time since discharge for HF patients in usual care

Time since discharge (in months)	Mortality Probability per month	Lower 95% confidence interval (CI)	Upper 95% CI
0–1	0.04622	0.03616	0.05891
1–3	0.03306	0.02644	0.04124
3–6	0.02674	0.02166	0.03306
6–12	0.02353	0.01964	0.02831
12–24	0.01866	0.01565	0.02226
>24	0.01467	0.01127	0.01911

The mean numbers of HF-related and other-cause hospitalisations (estimated as all-cause hospitalisations minus the HF-related hospitalisations) were estimated from a meta-analysis reported by Klersy *et al.*[11] The average number of monthly HF-related and all cause re-hospitalisations for patients in usual care are as shown in Table 2.

Table 2: Monthly risk of hospitalisations per patient in usual care

	Source	Estimate	Lower 95% CI	Upper 95% CI
HF-related hospitalisations	Klersy *et al.* [11]	0.0350	0.0325	0.0375
All-cause hospitalisations	Klersy *et al.* [11]	0.0875	0.0841	0.0908

Effectiveness of interventions

The effectiveness parameters in the economic model were the hazard ratios (HRs) for all-cause mortality, all-cause hospitalisations and HF-related hospitalisations for the different interventions (i.e. STS HM, STS HM and TM) against standard care. These effectiveness parameters were estimated from a network meta-analysis (NMA) of RM studies[8] and applied to the baseline parameters to estimate the hospitalisation and mortality risk parameters for the different interventions. It was assumed that the treatment effectiveness (and costs) lasts only for the treatment duration of six months, after which the baseline risks of hospitalisation and mortality were applied.

It should be noted that considerable heterogeneity was identified in the manner in which RM and usual care were performed among the studies included in the NMA,[8] which resulted in heterogeneity between studies in the estimate of HRs. For example, in RM, there was variation between studies in the type of devices used, parameters monitored and the protocols for triage and follow-up. In particular, the data from Dar *et al*[12] (Home-HF trial conducted in three district general hospitals in West London) appeared to be inconsistent with the data from the remaining studies because it showed a higher incidence of mortality among the TM group than the usual care group. However, the 6-month mortality rate in the usual care group (5.5%) was substantially lower than would be expected in an HF cohort receiving care outside the context of a clinical trial (that is, between 13% and 21%),[3] which the authors attributed to the high quality usual care (provided by a HF nurse specialist and a consultant with an interest in HF). The impact of this study was assessed in sensitivity analyses, and HRs from both of the NMAs are presented in Table 3.

Table 3: HRs for interventions versus usual care for all-cause mortality and hospitalisations

HRs for interventions versus usual care for mortality (all-cause) and hospitalisation (all-cause and HF) from NMA including Home-HF[12] study						
Type	**All-cause mortality**		**HF-hospitalisation**		**All-cause hospitalisation**	
	HR	**95% PrI**	**HR**	**95% PrI**	**HR**	**95% PrI**
STS HH	0.77	(0.31, 1.86)	0.77	(0.50, 1.19)	0.97	(0.38, 2.43)
STS HM	0.98	(0.30, 3.23)	1.03	(0.58, 1.77)	1.06	(0.31, 3.61)
TM	0.76	(0.30, 1.91)	0.95	(0.59, 1.62)	0.75	(0.28, 1.91)
HRs for interventions versus usual care for mortality (all-cause) and hospitalisation (all-cause and HF) from NMA excluding Home-HF[12] study						

STS HH	0.75	(0.45, 1.27)	0.76	(0.51, 1.13)	0.96	(0.42, 2.18)
STS HM	0.98	(0.49, 1.95)	1.02	(0.61, 1.69)	1.06	(0.35, 3.22)
TM	0.62	(0.35, 1.09)	0.86	(0.54, 1.38)	0.67	(0.26, 1.53)

HR, hazard ratio; PrI, predictive interval; STS HM, structured telephone support via human to machine interface; STS HH, structured telephone support via human to human contact; TM, telemonitoring

On deciding which of these results are most representative of their setting, the key questions for decision-makers relate to the inclusion of the Home-HF study[12] in the effectiveness meta-analyses. If one accepts that usual care is best represented by the usual care arm in the Home-HF study,[12] which is the only study showing a statistically significant difference in effectiveness of usual care over RM, then the results including Home-HF study[12] might be considered more relevant than those without. If on the other hand, one considers that the performance of usual care is better represented by the other studies and that usual care in Home-HF study[12] is not representative of current usual care, then the results excluding Home-HF study[12] might be more generalisable. This consideration predominantly affects the hazard ratios around the telemonitoring intervention only and does not impact significantly on the structure telephone service interventions.

Health-related quality of life

A review was conducted to estimate the health-related quality of life (HRQoL) and four studies were found [13-16], all of which reported utilities for recently discharged HF patients under usual care around 0.57 to 0.6. There was no quantified evidence on the extent to which RM improves HRQoL of the patients in the RM studies included in the NMA, thus, the same utility values were used for HF patients in both usual care and (each of the three) RM strategies in the economic model. The disutility caused by re-hospitalisation for HF was estimated as 0.1 based on a study by Yao et al,[17] who estimated the disutility to be equivalent to the utility of one health state lower in terms of NYHA class and this disutility was assumed to last for one year. In the absence of evidence regarding the disutility caused by re-hospitalisation for other causes (not directly HF-related), it was assumed that there was no disutility caused by re-hospitalisation for other causes.

A utility score of 0.58 was applied to the patients for each month in the first year after discharge and a utility of 0.67 was used after the first year. Any HF-related hospitalisation was assumed to result in a disutility of 0.1 for a whole year i.e. the utility of the patient for that year was 0.67-0.1 i.e. 0.57. Within the PSA, the uncertainty in the utility values were represented using a normal distribution using the deterministic values as mean with a standard deviation of 0.015, estimated based on the difference between utilities reported by Capomolla *et al*[13] and Iqbal *et al*,[15] while the disutility was represented using a triangular distribution with [-0.08,0.11] as the range with -0.1 as the mode.

Costs

The costs used in the model are a) costs of RM interventions after initial discharge only, b) costs of usual care and c) repeat hospitalisation costs. These costs are summarised in Table 4 and are described in detail in this section.

The RM studies did not report clearly or in detail what was involved in the usual post discharge care or RM, thus making it difficult to accurately determine the costs.[8] Due to the variation involved in the RM interventions and usual care, cost scenarios were developed for each RM classification (i.e. STS HM, STS HH and TM) and usual care. These costs were estimated using bottom-up costing methods for a typical health organisation of 250 HF patients (estimated based on median size of NHS Foundation Trusts in the UK) for a period of six months. Furthermore, it was assumed that after six months all patients would receive usual care as recommended in NICE clinical guidelines for the management of adults with CHF,[9] irrespective of whether they received the remote monitoring intervention or post discharge usual care during the intervention period.

It was assumed that the usual post discharge care was the same as that described in the TEN-HMS study[18] and the usual care costs were estimated by applying the hourly NHS staff rates from PSSRU 2011[19] to the resource use data in the TEN-HMS study.[18] A high cost usual post discharge care scenario was also developed based on discussions with the expert advisory group.

The total costs of RM interventions were broken down into the costs of the device, monitoring costs and medical care costs.[8] The costs of the RM devices were elicited from the expert advisory group. The monitoring costs were estimated using activity-based costing for the resources spent by staff on triage and follow-up based on evidence from the literature.[20] The costs of medical care were estimated by applying the hourly NHS staff rates from PSSRU 2011[19] to the resource use data in the TEN-HMS study,[18] which reported the medical care received in the usual care arm, STS and TM arms.

The mean inpatient admission cost for HF-related hospitalisations was calculated from the weighted average of the costs for the HRG "Heart Failure or Shock" (EB03H, EB03I) based on the data obtained from the NHS Reference Costs for 2011.[21] For hospital admissions for any cause other than HF, it was assumed that these costs were the same as the mean cost of hospital admission for the general population. This was estimated as a weighted average of elective inpatient admissions and non-elective inpatient admissions (including both short and long stay) based on the data from the NHS Reference Costs for 2011.[21]

Table 4: Cost parameters used in the economic model

Costs (in £) per six months	**Base case scenario**	**Low cost scenario**	**High cost scenario**	**Source**
UC	£161	-	£592	TEN-HMS,[18] Clinical opinion
STS HM	£715	£623	£794	Clinical opinion
STS HH	£1075	£1051	£1152	Clinical opinion
TM	£1051	£801	£1288	Clinical opinion
Usual care costs (per month) after six month intervention duration				
UC after six months	£8.23	-	-	NICE HF guidelines[9]
Hospitalisation costs	**Estimate**	**Lower 95% CI**	**Upper 95% CI**	
HF-related hospitalisations[a]	£2,514.49	£1,857	£2,809	NHS Reference Costs for 2011[21]

Other-cause hospitalisations[b]	£1,529.79	£1,129	£1,709	NHS Reference Costs for 2011[21]

[a] Heart failure or shock (EB03H EB03I): Non-elective inpatient (long stay) including excess bed days[21]
[b] Non-elective inpatient (long and short stay) including excess bed days[21]

RESULTS

The results of the cost-effectiveness analysis using base case costs are presented in Table 5 for both estimates of effectiveness, including and excluding data from the Home-HF study,[12] to address the uncertainty in the effectiveness evidence. Results are also presented for five cost scenarios (higher usual care cost scenario, lower cost scenario of TM, higher cost scenario of TM, lower STS cost scenario and higher STS cost scenario) and the 12 month intervention duration scenario in supplementary Tables 1 and 2, respectively.

Table 5: Summary of the economic analysis results using base case costs

	Usual care	STS HM	STS HH	TM
Total costs				
Including Home-HF[12]	£8,478	£8,965	£9,574	£9,437
Excluding Home-HF[12]	£8,478	£9,087	£9,658	£9,665
Total QALYs				
Including Home-HF[12]	2.4137	2.3633	2.4950	2.4944
Excluding Home-HF[12]	2.4137	2.4043	2.5230	2.5847
ICERs				
Including Home-HF[12]		Dominated	£228,035[a]	£11,873
Excluding Home-HF[12]		Dominated	Extendedly dominated	£6,942[a]
Probability of cost-effectiveness				
Including Home-HF[12]	6%	19%	35%	40%
Excluding Home-HF[12]	1%	7%	19%	73%

STS HM, structured telephone support via human to machine interface; STS HH, structured telephone support via human to human contact; TM, telemonitoring; UC, usual care; QALYs, quality adjusted life years; NB, net benefit; ICERs, incremental cost-effectiveness ratios

[a] last strategy in the cost-effectiveness frontier

In the analysis using base case costs, TM is the most cost-effective strategy at a threshold of £20,000/QALY in both analyses i.e. including and excluding the Home-HF study.[12] TM is also the most effective strategy (i.e. highest QALYs gained) in the analyses that excluded the Home-HF study,[12] but not in the analyses that included Home-HF study,[12] with STS HH providing the highest number of expected QALYs. However, the additional QALYs gained by STS HH are not worth the additional costs of the strategy as seen in the ICERs (against TM) greater than the threshold of £20,000/QALY.

In the analyses that included the Home-HF study,[12] there is only a 40% chance of TM being cost-effective at the threshold of £20,000/QALY, as shown in Figure 1. Excluding the Home-HF study,[12] the probability that TM during office hours is cost-effective increases to 73% (Figure 2).

Figure 1: CEAC for basecase economic analysis using effectiveness data including Home-HF study[12]

Figure 2: CEAC for economic analysis using effectiveness data excluding Home-HF study[12]

Scenario analyses performed using higher costs of usual care, higher costs of STS HH and lower costs of TM do not substantially change the conclusions. TM was estimated to be the most cost-effective strategy in all these scenarios. Scenario analysis performed using higher costs of TM (£215 per month) suggested that TM is dominated by STS HH. This is because a small change in the difference between costs of TM and STS HH led to a marked change in ICERs, given the small difference (0.0021 QALYs) in expected QALYs between STS HH and TM in the analyses that included the Home-HF study.[12] However, the same scenario analysis (i.e. higher cost of TM of £215 per month) that excluded the data from Home-HF study,[12] suggested that TM is still the most cost-effective strategy with an ICER of £7,854/QALY against usual care (STS HH is extendedly dominated by a combination of usual care and TM). This is due to the much higher difference in the expected QALYs between STS HH and TM (0.0602 QALYs), where a small change in the difference between costs of TM and STS HH can not lead to a marked change in the ICER. Threshold analysis suggested that the monthly cost of TM has to be higher than £390 per month to have an ICER greater £20,000/QALY against STS HH. The ICER of TM against usual care, at this monthly cost of £390, is £13,357/QALY.

Scenario analysis using 12 month treatment duration produced similar results as in the six month treatment duration scenarios. TM for 12 months was also cost-effective when compared against TM for six months with an ICER of £12,213/QALY. However, treating 2*N patients using TM for six months was cost-effective with an ICER of £793/QALY against a combination of treating N patients using TM for 12 months with the rest of the N patients under usual care.

DISCUSSION

The results of the base case cost-effectiveness analyses suggest that TM is expected to be the most cost-effective strategy at a threshold of £20,000/QALY. However, there is uncertainty involved in suggesting that TM is the most probable cost-effective strategy and in particular, there is greater uncertainty when data from Home-HF study[12] is included than when it is excluded. For decision makers, the key question is whether the usual care in their local setting is similar to the usual care arm in the Home-HF study.[12] If so, then the results including Home-HF study[12] might be considered more relevant and if not, results excluding Home-HF study[12] might be considered more relevant. Scenario analysis performed (using higher usual care costs, lower TM costs, higher TM costs and higher STS costs) did not substantially change the conclusions, TM was estimated to be the most cost-effective strategy in all these scenarios. Furthermore, TM for 12 months was also cost-effective when compared against TM for six months, which suggests that it is cost-effective to keep the patients on TM beyond six months. In situations with a limited number of TM devices, it is cost-effective to treat all patients using TM for six months than using TM for 12 months on half the patients with the other half of the patients under usual care.

There have been two cost-effectiveness analyses studies of RM in HF, but neither considered the different RM approaches separately.[11,22] The analysis reported by Miller *et al.*[22] was based on a single trial of STS,[23] whereas Klersy *et al*[11] included data from a meta-analysis of a wide range of RM studies. Miller *et al*[22] estimated that STS compared with usual care had an ICER around $43,650 per QALY, this study did not perform a PSA, but only univariate sensitivity analyses (ICER varying from $28,691 to $129,738). Klersy *et al*[11] focused mainly on the effectiveness rather than the costs and used a time horizon of one year. A budget impact analysis was presented and the different diagnosis-related group (DRG) reimbursement tariff groups, as proxy for hospitalisations costs, were considered with cost savings per patient ranging between €306.8 and €992.94. However, other costs such as RM costs and outpatient visit costs were not considered. The authors performed scenario analyses using different DRG costs as part of the budget analysis to address the uncertainty in the hospitalisation costs, but neither deterministic sensitivity analysis nor PSA were performed.

Whole Systems Demonstrator (WSD) Programme,[24] a randomised controlled trial of telehealth that included over 6,000 patients, analysed costs and outcomes for 965 patients monitored for 12 months: 534 receiving telehealth and 431 receiving usual care. Cost-effectiveness analysis estimated the ICER £92,000/QALY when telehealth when added to usual care for people with chronic conditions (diabetes, HF, and COPD). However, this trial based evaluation (with a time horizon of 1 year) potentially underestimates the health benefits as it does not include the long-term QALYs gained from the reduction in mortality. Furthermore, the WSD analysis included all patients with chronic conditions (diabetes, HF, and COPD) whereas the population under consideration in our analysis are patients who are recently discharged with HF. The cost-effectiveness results for HF patients are not yet publically available in a peer-reviewed journal and thus, it is difficult to compare the results of the current analysis with the results of the WSD analysis.

The analysis reported in this paper also has some limitations that need to be taken into account. Any modelling process involves simplifications and assumptions that may not accurately reflect clinical practice. Due to the lack of detail provided in research studies included in the NMA concerning the components of RM packages and usual care (e.g. communication protocols, routine staff visits, and resources used), scenarios for different RM classifications were developed and their costs were estimated using bottom-up costing methods. Although the users can decide which of these analyses is most representative of their setting, uncertainties still remain about the assumptions made in the estimation of these costs. However, it should be noted that the monthly costs estimated were similar to those reported in the WSD. Implementation costs (such as set-up costs, staff training costs, service reconfiguration costs, costs for dual running of usual care and RM services) were not included in the model but are often a consideration for the health organisations.

RM interventions included in the NMA were heterogeneous in terms of monitored parameters and selection criteria for HF; this was the case even within specific types of RM (STS HH, STS HM, and TM) and is reflected in the uncertainty of the effectiveness parameters. A limitation of the analyses is that the effectiveness parameters remained the same for the different cost scenarios whereas in reality there might be some correlation between the costs and effectiveness of different RM strategies. Also, it was assumed that the effectiveness and costs of the interventions are constant over time, irrespective of the duration of deployment. Furthermore, as the analysis is not severity specific, it assumes that the interventions are equally effective in different severity groups within the population under consideration (i.e. patients who are recently discharged with HF). Repeat interventions after repeat hospital admissions for heart failure are not modelled as the model complexity would increase beyond practical analyses.

Some of the assumptions above may not hold true in reality and further research is needed to address these issues. Given the complex nature of RM interventions, new research should seek to examine the 'active ingredients' of RM and identify patient subgroups that can benefit most from the intervention and in which patients these interventions are unlikely to be effective. In addition, usual care ought to be more robustly determined, reflecting best practice as defined in the current guidelines, although this is not commonly the case. Furthermore, to aid robust cost-effectiveness estimations, the costs associated with usual care and RM interventions need to be reported in detail (including the costs of HF treatment pathways) and QoL needs to be reported with observations at specific time points in order to estimate the difference in the utility of the patients between the RM and usual care groups. Future studies should provide greater detail on reconfiguration and set up costs and link more clearly with the financial impact (e.g. cost variation with scale and over time) on provider organisations. Wider adaptation of RM in the NHS can be facilitated by providing financial impact data (e.g. quarterly costs of service, costs of reconfiguration) along with the cost-effectiveness information.

The results of the current analysis have important implications for the healthcare systems facing rising demand from emergency admissions. HF is a leading cause of hospitalisation in the UK, with 58,164 admissions recorded for HF (as first diagnoses) between April 2009 to March 2010 in England and Wales.[25] The cost of inpatient bed days for HF alone has been estimated at £563 million,[26] with around 90% of HF admissions to emergency departments,[27] lasting a median of nine days.[25] The evidence shows that use of RM could substantially reduce HF admissions, with an associated reduction in pressure on acute beds, and consequent cost savings. Furthermore, the use of TM allows the potential transfer from emergency admission to elective admission i.e. scheduling admissions of patients directly (not via A&E) to either a ward or to a day unit for offloading, leading to major resource savings, with less patient disutility.

Indeed, the Department of Health (DH) recognised this potential and launched an initiative, "3 Million Lives" (3ML), to help at least three million people with long term conditions and/or social care to benefit from the use of telehealth and telecare services[28]. A concordat has been entered into by the DH and the telehealth and telecare industry to work together to accelerate the use of TM[29]. Thus far, seven pathfinder sites have agreed contracts with industry to ensure that 100,000 people benefit from technology in 2013[30]. Implemented effectively as part of a whole system redesign of care, TM can alleviate pressure on long term NHS costs and improve people's quality of life through better self-care in the home setting.

Contributors PT developed the decision analytical model, undertook the analysis and drafted the paper. HB assisted in parameter searching, model development and analysis. AB provided expert modelling advice. AP was responsible for conception and design, undertook the systematic review along with TG and provided data for the meta-analysis. JWS and JW provided meta-analysis results and statistical input. AB, AAM, JC and MRC provided expert clinical input. RW developed and undertook the literature searches. All authors commented on the draft/final paper.

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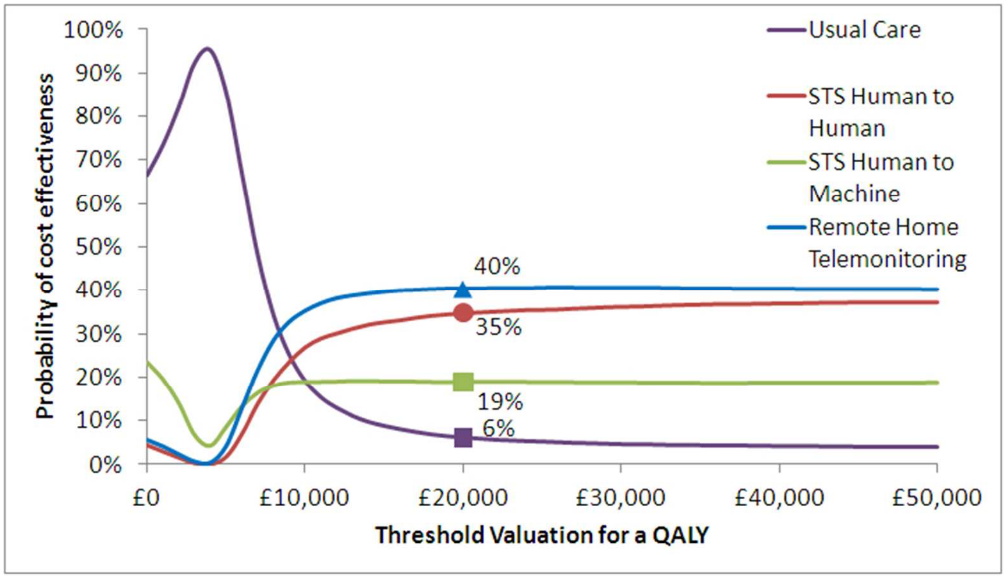

Figure 1: CEAC for basecase economic analysis using effectiveness data including Home-HF study
189x109mm (96 x 96 DPI)

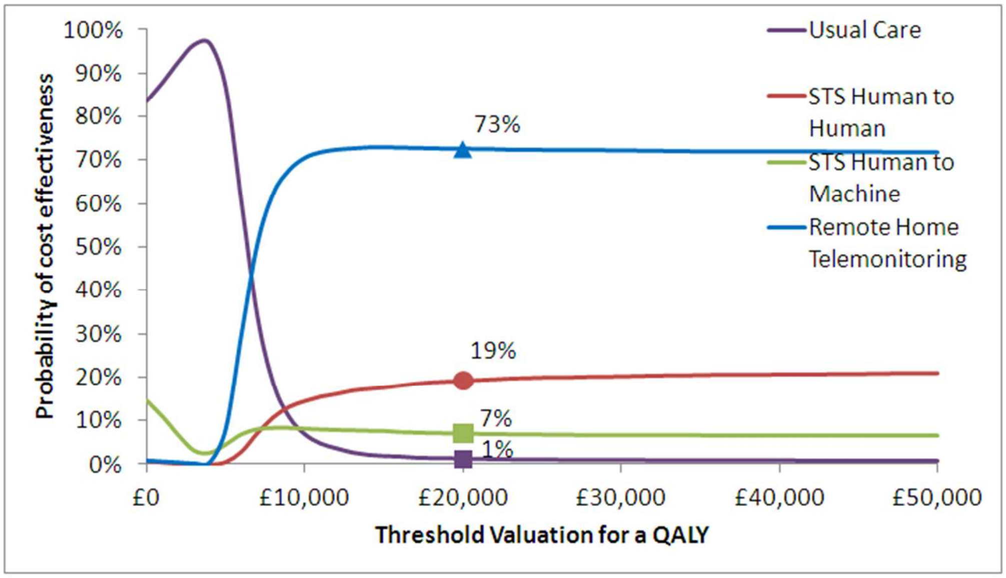

Figure 2: CEAC for economic analysis using effectiveness data excluding Home-HF study
189x109mm (96 x 96 DPI)

TELEMONITORING AFTER DISCHARGE FROM HOSPITAL WITH HEART FAILURE - COST-EFFECTIVENESS MODELLING OF ALTERNATIVE SERVICE DESIGNS

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TELEMONITORING AFTER DISCHARGE FROM HOSPITAL WITH HEART FAILURE - COST-EFFECTIVENESS MODELLING OF ALTERNATIVE SERVICE DESIGNS

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ABSTRACT

OBJECTIVES: To estimate the cost-effectiveness of remote monitoring strategies versus usual care for adults recently discharged after a heart failure (HF) exacerbation.

DESIGN: Decision analysis modelling of cost-effectiveness using secondary data sources.

SETTING: Acute hospitals in the United Kingdom.

PATIENTS: Patients recently discharged (within 28 days) after a heart failure (HF) exacerbation

INTERVENTIONS: Structured telephone support (STS) via human to machine (STS HM) interface, b) STS via human to human (STS HH) contact, and c) home telemonitoring (TM), compared against d) usual care.

MAIN OUTCOME MEASURES: The incremental cost per quality-adjusted life year (QALY) gained by each strategy compared to the next most effective alternative and the probability of each strategy being cost-effective at varying willingness to pay per QALY gained.

RESULTS: TM was the most cost-effective strategy in the scenario using these base case costs. Compared with usual care, TM had an estimated incremental cost effectiveness ratio (ICER) of £11,873/QALY, whereas STS HH had an ICER of £228,035/QALY against TM. STS HM was dominated by usual care. Threshold analysis suggested that the monthly cost of TM has to be higher than £390 to have an ICER greater than £20,000/QALY against STS HH. Scenario analyses performed using higher costs of usual care, higher costs of STS HH and lower costs of TM do not substantially change the conclusions.

CONCLUSIONS: Cost-effectiveness analyses suggest TM was an optimal strategy in most scenarios, but there is considerable uncertainty in relation to clear descriptions of the interventions and robust estimation of costs.

BACKGROUND

Heart failure (HF) is associated with high levels of morbidity and mortality, with the highest risk immediately after discharge from hospital.[1] 20-30% of patients are readmitted within 30 days, rising to 50% at six months.[2] Patients who are discharged have around 28% risk of mortality within the first year after HF discharge.[3] Strategies to slow disease progression are needed for at-risk patients, to improve the prognosis, even among those receiving optimal pharmaceutical therapy.[4]

Remote monitoring (RM) of indicators of deterioration (e.g. weight, arrhythmia, blood pressure, intrathoracic impedance, heart rates during rest and exertion, and symptom control) can facilitate early detection of clinically significant changes and thus earlier intervention to restabilise the syndrome, prevent emergency admissions, and avoid complications.[5] RM can be broadly classified into telemonitoring (TM), in which physiological data are electronically transmitted to a healthcare team, and structured telephone support (STS), that is, the use of phone calls, usually by specialist nurses, to deliver self-care support and/or management.[6] For STS, support can be provided by human-to-human contact (HH), or via a human-to-machine interface (HM); that is, STS with an interactive response system (e.g. a voice-interactive system). For TM, support can be provided during office hours only or 24 hours per day, seven days per week (24/7), though few studies have used the latter approach.

The cost-effectiveness of a RM strategy can be estimated by comparing the outcomes and costs associated with the strategy to the next most effective alternative. If these outcomes are estimated as quality-adjusted life years (QALYs) then the incremental cost-effectiveness ratio (ICER), or cost per QALY gained, can be calculated and compared to alternative uses of health care funding. In the United Kingdom (UK), NICE typically recommends in favour of funding interventions with an ICER below thresholds of £20,000/QALY, requires considerable clinical benefit to recommend funding interventions between £20,000 and £30,000/QALY, and recommends against funding interventions with an ICER above these thresholds. The aim of this paper is to estimate the incremental cost per QALY of RM strategies compared with usual care, so as to determine which RM strategy should be recommended according to typical NICE thresholds for cost-effectiveness.

METHODS

Model scope

A Markov model was developed using MS Excel software (Microsoft Corporation) to estimate the cost-effectiveness of remote monitoring (RM) interventions with usual care for patients discharged in the past 28 days with a HF-related hospitalisation,[7] measured as the incremental cost per QALY gained by each strategy compared with the next most effective alternative on the cost-effectiveness frontier. Cost-effectiveness results are estimated as mean values of 10,000 probabilistic sensitivity analysis (PSA) runs, with each PSA run using different estimates for the risks, hazard ratios, costs and utilities sampled from probability distributions representing uncertainty in the parameter estimates. Additionally, the probability that each strategy would be the most cost-effective was calculated at different thresholds for willingness to pay (WTP) for health gain. Cost-effectiveness acceptability curves were constructed by plotting the probability of each strategy being cost-effective against WTP threshold.

The following strategies post discharge interventions were tested in the model:

a) Usual care
b) STS HH (structured telephone support with human-to-human contact)
c) STS HM (structured telephone support with human-to-machine interface) and
d) TM (i.e. telemonitoring with transmitted data reviewed by medical staff or medical support provided during office hours)

The clinical effectiveness parameters of these three RM strategies were estimated from a network meta-analysis of the available evidence,[8] and costs were estimated using ‘bottom up’ costing methods. It was assumed that the interventions were provided for the six months following discharge from the hospital, as the majority of the RM trials included in the network meta-analysis used a six month follow-up duration.[8] At the end of six months all patients were assumed to receive usual care as per the NICE Clinical Guidelines for the Management of Adults with Chronic Heart

Failure,[9] irrespective of whether they received intervention or post discharge usual care during the treatment period.

Model structure

In the Markov model, two different states were considered:

(a) Alive at home
(b) Dead

The Markov model used a monthly cycle length with half-cycle correction and assigned each patient with a monthly probability of death based on the time since discharge and the type of treatment. In each period, the patients that were alive were under the risk of an average number of monthly re-hospitalisations i.e. readmissions to a hospital for HF or other causes. Each patient then accrued lifetime QALYs and health care costs according to their hospitalisation and treatment status. The model used a 30 year (patient lifetime) horizon although the impact of each intervention was for the first six months after an initial discharge. Both the costs and QALYs were discounted at an annual discount rate of 3.5% and the economic perspective of the model was that of NHS in England and Wales. Repeat interventions after repeat hospitalisations were not considered in this model.

Baseline mortality and hospitalisation

The baseline monthly probabilities of death were estimated from the Candesartan in Heart failure: Assessment of Reduction in Mortality and morbidity (CHARM) study,[10] which included 7572 patients with mean age of 65.5 years followed up for 38 months, as it assessed the influence of non-fatal hospitalisation for heart failure on subsequent mortality. The data from the CHARM study[10] showed that the mortality risk was highest immediately after hospital discharge and then decreased over time, as shown in Table 1.

Table 1: Monthly mortality probability vs. time since discharge for HF patients in usual care

Time since discharge (in months)	Mortality Probability per month	Lower 95% confidence interval (CI)	Upper 95% CI
0–1	0.04622	0.03616	0.05891
1–3	0.03306	0.02644	0.04124
3–6	0.02674	0.02166	0.03306
6–12	0.02353	0.01964	0.02831
12–24	0.01866	0.01565	0.02226
>24	0.01467	0.01127	0.01911

The mean numbers of HF-related and other-cause hospitalisations (estimated as all-cause hospitalisations minus the HF-related hospitalisations) were estimated from a meta-analysis of 21 studies (5715 patients, median age 70.7 ranging from 45 to 78 years) reported by Klersy *et al.*[11] The average number of monthly HF-related and all cause re-hospitalisations for patients in usual care are as shown in Table 2.

Table 2: Monthly risk of hospitalisations per patient in usual care

	Source	Estimate	Lower 95% CI	Upper 95% CI
HF-related hospitalisations	Klersy *et al.* [11]	0.0350	0.0325	0.0375
All-cause hospitalisations	Klersy *et al.* [11]	0.0875	0.0841	0.0908

Effectiveness of interventions

The effectiveness parameters in the economic model were the hazard ratios (HRs) for all-cause mortality, all-cause hospitalisations and HF-related hospitalisations for the different interventions (i.e. STS HM, STS HM and TM) against standard care. These effectiveness parameters were estimated from a network meta-analysis (NMA) of 21 RM studies[8] (total 6317 patients, with mean age across studies ranging from 57 to 78 years) and applied to the baseline parameters to estimate the hospitalisation and mortality risk parameters for the different interventions. It was assumed that the treatment effectiveness (and costs) lasts only for the treatment duration of six months, after which the baseline risks of hospitalisation and mortality were applied.

It should be noted that considerable heterogeneity was identified in the manner in which RM and usual care were performed among the studies included in the NMA,[8] which resulted in heterogeneity between studies in the estimate of HRs. For example, in RM, there was variation between studies in the type of devices used, parameters monitored and the protocols for triage and follow-up. In particular, the data from Dar *et al*[12] (Home-HF trial conducted in three district general hospitals in West London) appeared to be inconsistent with the data from the remaining studies because it showed a higher incidence of mortality among the TM group than the usual care group. However, the 6-month mortality rate in the usual care group (5.5%) was substantially lower than would be expected in an HF cohort receiving care outside the context of a clinical trial (that is, between 13% and 21%),[3] which the authors attributed to the high quality usual care (provided by a HF nurse specialist and a consultant with an interest in HF). The impact of this study was assessed in sensitivity analyses, and HRs from both of the NMAs are presented in Table 3.

Table 3: HRs for interventions versus usual care for all-cause mortality and hospitalisations

HRs for interventions versus usual care for mortality (all-cause) and hospitalisation (all-cause and HF) from NMA including Home-HF[12] study

Type	All-cause mortality		HF-hospitalisation		All-cause hospitalisation	
	HR	95% PrI	HR	95% PrI	HR	95% PrI
STS HH	0.77	(0.31, 1.86)	0.77	(0.50, 1.19)	0.97	(0.38, 2.43)

STS HM	0.98	(0.30, 3.23)	1.03	(0.58, 1.77)	1.06	(0.31, 3.61)
TM	0.76	(0.30, 1.91)	0.95	(0.59, 1.62)	0.75	(0.28, 1.91)
HRs for interventions versus usual care for mortality (all-cause) and hospitalisation (all-cause and HF) from NMA excluding Home-HF[12] study						
STS HH	0.75	(0.45, 1.27)	0.76	(0.51, 1.13)	0.96	(0.42, 2.18)
STS HM	0.98	(0.49, 1.95)	1.02	(0.61, 1.69)	1.06	(0.35, 3.22)
TM	0.62	(0.35, 1.09)	0.86	(0.54, 1.38)	0.67	(0.26, 1.53)

HR, hazard ratio; PrI, predictive interval; STS HM, structured telephone support via human to machine interface; STS HH, structured telephone support via human to human contact; TM, telemonitoring

On deciding which of these results are most representative of their setting, the key questions for decision-makers relate to the inclusion of the Home-HF study[12] in the effectiveness meta-analyses. If one accepts that usual care is best represented by the usual care arm in the Home-HF study,[12] which is the only study showing a statistically significant difference in effectiveness of usual care over RM, then the results including Home-HF study[12] might be considered more relevant than those without. If on the other hand, one considers that the performance of usual care is better represented by the other studies and that usual care in Home-HF study[12] is not representative of current usual care, then the results excluding Home-HF study[12] might be more generalisable. This consideration predominantly affects the hazard ratios around the telemonitoring intervention only and does not impact substantially on the structure telephone service interventions.

Health-related quality of life

A review was conducted to estimate the health-related quality of life (HRQoL) and four studies were found [13-16], all of which reported utilities for recently discharged HF patients under usual care around 0.57 to 0.6. There was no quantified evidence on the extent to which RM improves HRQoL of the patients in the RM studies included in the NMA, thus, the same utility values were used for HF patients in both usual care and (each of the three) RM strategies in the economic model. The disutility caused by re-hospitalisation for HF was estimated as 0.1 based on a study by Yao et al,[17] who estimated the disutility to be equivalent to the utility of one health state lower in terms of New York Heart Association (NYHA) class and this disutility was assumed to last for one year. In the absence of evidence regarding the disutility caused by re-hospitalisation for other causes (not directly HF-related), it was assumed that there was no disutility caused by re-hospitalisation for other causes.

A utility score of 0.58 was applied to the patients for each month in the first year after discharge and a utility of 0.67 was used after the first year. Any HF-related hospitalisation was assumed to result in a disutility of 0.1 for a whole year i.e. the utility of the patient for that year was 0.67-0.1 i.e. 0.57. Within the PSA, the uncertainty in the utility values were represented using a normal distribution using the deterministic values as mean with a standard deviation of 0.015, estimated based on the difference between utilities reported by Capomolla *et al*[13] and Iqbal *et al*,[15] while the disutility was represented using a triangular distribution with [-0.08,0.11] as the range with -0.1 as the mode.

Costs

The costs used in the model are a) costs of RM interventions after initial discharge only, b) costs of usual care and c) repeat hospitalisation costs. These costs are summarised in Table 4 and are described in detail in this section.

The RM studies did not report clearly or in detail what was involved in the usual post discharge care or RM, thus making it difficult to accurately determine the costs.[8] Due to the variation involved in the RM interventions and usual care, cost scenarios were developed for each RM classification (i.e. STS HM, STS HH and TM) and usual care. These costs were estimated using bottom-up costing methods for a typical health organisation of 250 HF patients (estimated based on median size of NHS Foundation Trusts in the UK) for a period of six months. Furthermore, it was assumed that after six months all patients would receive usual care as recommended in NICE clinical guidelines for the management of adults with CHF,[9] irrespective of whether they received the remote monitoring intervention or post discharge usual care during the intervention period.

It was assumed that the usual post discharge care was the same as that described in the TEN-HMS study[18] and the usual care costs were estimated by applying the hourly NHS staff rates from PSSRU 2011[19] to the resource use data in the TEN-HMS study.[18] A high cost usual post discharge care scenario was also developed based on discussions with the clinical expert group (AB, AAM, JC and MRC).

The total costs of RM interventions were broken down into the costs of the device, monitoring costs and medical care costs.[8] The costs of the RM devices were elicited from the expert advisory group. The monitoring costs were estimated using activity-based costing for the resources spent by staff on triage and follow-up based on evidence from the literature.[20] The costs of medical care were estimated by applying the hourly NHS staff rates from PSSRU 2011[19] to the resource use data in the TEN-HMS study,[18] which reported the medical care received in the usual care arm, STS and TM arms.

The mean inpatient admission cost for HF-related hospitalisations was calculated from the weighted average of the costs for the HRG "Heart Failure or Shock" (EB03H, EB03I) based on the data obtained from the NHS Reference Costs for 2011.[21] For hospital admissions for any cause other than HF, it was assumed that these costs were the same as the mean cost of hospital admission for the general population. This was estimated as a weighted average of elective inpatient admissions and non-elective inpatient admissions (including both short and long stay) based on the data from the NHS Reference Costs for 2011.[21]

Table 4: Cost parameters used in the economic model

Costs (in £) per six months	Base case scenario	Low cost scenario	High cost scenario	Source
UC	£161	-	£592	TEN-HMS,[18] Clinical opinion
STS HM	£715	£623	£794	Clinical opinion
STS HH	£1075	£1051	£1152	Clinical opinion
TM	£1051	£801	£1288	Clinical opinion

Usual care costs (per month) after six month intervention duration				
UC after six months	£8.23	-	-	NICE HF guidelines[9]
Hospitalisation costs	**Estimate**	**Lower 95% CI**	**Upper 95% CI**	
HF-related hospitalisations[a]	£2,514.49	£1,857	£2,809	NHS Reference Costs for 2011[21]
Other-cause hospitalisations[b]	£1,529.79	£1,129	£1,709	NHS Reference Costs for 2011[21]

[a] Heart failure or shock (EB03H EB03I): Non-elective inpatient (long stay) including excess bed days[21]
[b] Non-elective inpatient (long and short stay) including excess bed days[21]

RESULTS

The results of the cost-effectiveness analysis using base case costs are presented in Table 5 for both estimates of effectiveness, including and excluding data from the Home-HF study,[12] to address the uncertainty in the effectiveness evidence. Results are also presented for five cost scenarios (higher usual care cost scenario, lower cost scenario of TM, higher cost scenario of TM, lower STS cost scenario and higher STS cost scenario) and the 12 month intervention duration scenario in supplementary Tables 1 and 2, respectively.

Table 5: Summary of the economic analysis results using base case costs

	Usual care	STS HM	STS HH	TM
Total costs				
Including Home-HF[12]	£8,478	£8,965	£9,574	£9,437
Excluding Home-HF[12]	£8,478	£9,087	£9,658	£9,665
Total QALYs				
Including Home-HF[12]	2.4137	2.3633	2.4950	2.4944
Excluding Home-HF[12]	2.4137	2.4043	2.5230	2.5847
ICERs				
Including Home-HF[12]		Dominated	£228,035[a]	£11,873
Excluding Home-HF[12]		Dominated	Extendedly dominated	£6,942[a]
Probability of cost-effectiveness				
Including Home-HF[12]	6%	19%	35%	40%
Excluding Home-HF[12]	1%	7%	19%	73%

STS HM, structured telephone support via human to machine interface; STS HH, structured telephone support via human to human contact; TM, telemonitoring; QALYs, quality adjusted life years; ICERs, incremental cost-effectiveness ratios
[a] last strategy in the cost-effectiveness frontier

In the analysis using base case costs, TM is the most cost-effective strategy at a threshold of £20,000/QALY in both analyses i.e. including and excluding the Home-HF study.[12] TM is also the most effective strategy (i.e. highest QALYs gained) in the analyses that excluded the Home-HF study,[12] but not in the analyses that included Home-HF study,[12] with STS HH providing the highest number of expected QALYs. However, the additional QALYs gained by STS HH are not worth the additional costs of the strategy as seen in the ICERs (against TM) greater than the threshold of £20,000/QALY.

In the analyses that included the Home-HF study,[12] there is only a 40% chance of TM being cost-effective at the threshold of £20,000/QALY, as shown in Figure 1. Excluding the Home-HF study,[12] the probability that TM during office hours is cost-effective increases to 73% (Figure 2).

Figure 1: CEAC for basecase economic analysis using effectiveness data including Home-HF study[12]

Figure 2: CEAC for economic analysis using effectiveness data excluding Home-HF study[12]

Scenario analyses performed using higher costs of usual care, higher costs of STS HH and lower costs of TM do not substantially change the conclusions. TM was estimated to be the most cost-effective strategy in all these scenarios. Scenario analysis performed using higher costs of TM (£215 per month) suggested that TM is dominated by STS HH. This is because a small change in the difference between costs of TM and STS HH led to a marked change in ICERs, given the small difference (0.0021 QALYs) in expected QALYs between STS HH and TM in the analyses that included the Home-HF study.[12] However, the same scenario analysis (i.e. higher cost of TM of £215 per month) that excluded the data from Home-HF study,[12] suggested that TM is still the most cost-effective strategy with an ICER of £8,223/QALY against usual care (STS HH is extendedly dominated by a combination of usual care and TM). This is due to the much higher difference in the expected QALYs between STS HH and TM (0.0602 QALYs), where a small change in the difference between costs of TM and STS HH can not lead to a marked change in the ICER. Threshold analysis suggested that the monthly cost of TM has to be higher than £390 per month to have an ICER greater £20,000/QALY against STS HH. The ICER of TM against usual care, at this monthly cost of £390, is £13,357/QALY.

Scenario analyses performed using different estimates of the disutility for HF-related and other cause hospitalisations produced results similar to that in the basecase analysis i.e. the results are robust to the variations in the disutility of hospitalisations.

Scenario analysis using 12 month treatment duration produced similar results as in the six month treatment duration scenarios. TM for 12 months was also cost-effective when compared against TM for six months with an ICER of £14,066/QALY. However, treating 2**N* patients using TM for six months was cost-effective with it dominant against a combination of treating *N* patients using TM for 12 months with the rest of the *N* patients under usual care.

DISCUSSION

The results of the base case cost-effectiveness analyses suggest that TM is expected to be the most cost-effective strategy at a threshold of £20,000/QALY. However, there is uncertainty involved in suggesting that TM is the most probable cost-effective strategy and in particular, there is greater uncertainty when data from Home-HF study[12] is included than when it is excluded. For decision makers, the key question is whether the usual care in their local setting is similar to the usual care arm in the Home-HF study.[12] If so, then the results including Home-HF study[12] might be considered more relevant and if not, results excluding Home-HF study[12] might be considered more relevant. Scenario analysis performed (using higher usual care costs, lower TM costs, higher TM costs and higher STS costs) did not substantially change the conclusions, TM was estimated to be the most cost-effective strategy in all these scenarios. Furthermore, TM for 12 months was also cost-effective when compared against TM for six months, which suggests that it is cost-effective to keep the patients on TM beyond six months. In situations with a limited number of TM devices, assuming a homogenous patient group, it is cost-effective to treat all patients using TM for six months than using TM for 12 months on half the patients with the other half of the patients under usual care.

There have been two cost-effectiveness analyses studies of RM in HF, but neither considered the different RM approaches separately.[11,22] The analysis reported by Miller *et al.*[22] was based on a single trial of STS,[23] whereas Klersy *et al*[11] included data from a meta-analysis of a wide range of RM studies. Miller *et al*[22] estimated that STS compared with usual care had an ICER around $43,650 per QALY, this study did not perform a PSA, but only univariate sensitivity analyses (ICER varying from $28,691 to $129,738). Klersy *et al*[11] focused mainly on the effectiveness rather than the costs and used a time horizon of one year. A budget impact analysis was presented and the different diagnosis-related group (DRG) reimbursement tariff groups, as proxy for hospitalisations costs, were considered with cost savings per patient ranging between €306.8 and €992.94. However, other costs such as RM costs and outpatient visit costs were not considered. The authors performed scenario analyses using different DRG costs as part of the budget analysis to address the uncertainty in the hospitalisation costs, but neither deterministic sensitivity analysis nor PSA were performed.

Whole Systems Demonstrator (WSD) Programme,[24] a randomised controlled trial of telehealth that included over 6,000 patients, analysed costs and outcomes for 965 patients monitored for 12 months: 534 receiving telehealth and 431 receiving usual care. Cost-effectiveness analysis estimated the ICER £92,000/QALY when telehealth when added to usual care for people with chronic conditions (diabetes, HF, and COPD). However, this trial based evaluation (with a time horizon of 1 year) potentially underestimates the health benefits as it does not include the long-term QALYs gained from the reduction in mortality. Furthermore, the WSD analysis included all patients with chronic conditions (diabetes, HF, and COPD) whereas the population under consideration in our analysis are patients who are recently discharged with HF. The cost-effectiveness results for HF patients are not yet publically available in a peer-reviewed journal and thus, it is difficult to compare the results of the current analysis with the results of the WSD analysis.

The analysis reported in this paper also has some limitations that need to be taken into account. Any modelling process involves simplifications and assumptions that may not accurately reflect clinical practice. Due to the lack of detail provided in research studies included in the NMA concerning the components of RM packages and usual care (e.g. communication protocols, routine staff visits, and resources used), scenarios for different RM classifications were developed and their costs were estimated using bottom-up costing methods. Although the users can decide which of these analyses is most representative of their setting, uncertainties still remain about the assumptions made in the estimation of these costs. However, it should be noted that the monthly costs estimated were similar to those reported in the WSD. Implementation costs (such as set-up costs, staff training costs, service reconfiguration costs, costs for dual running of usual care and RM services) were not included in the model but are often a consideration for the health organisations.

RM interventions included in the NMA were heterogeneous in terms of monitored parameters and selection criteria for HF; this was the case even within specific types of RM (STS HH, STS HM, and TM) and is reflected in the uncertainty of the effectiveness parameters. A limitation of the analyses is that the effectiveness parameters remained the same for the different cost scenarios whereas in reality there might be some correlation between the costs and effectiveness of different RM strategies. Also, it was assumed that the effectiveness and costs of the interventions are constant over time, irrespective of the duration of deployment. Furthermore, as the analysis is not severity specific, it assumes that the interventions are equally effective in different severity groups within the population under consideration (i.e. patients who are recently discharged with HF). Repeat interventions after repeat hospital admissions for heart failure are not modelled and the mortality risk is not reset for patients who are re-admitted as this would need detailed evidence on baseline risks and effectiveness in different patient groups. As this detailed evidence is not available, the cohort model uses evidence about the overall average of the patients to estimate the cost-effectiveness.

Some of the assumptions above may not hold true in reality and further research is needed to address these issues. Given the complex nature of RM interventions, new research should seek to examine the 'active ingredients' of RM and identify patient subgroups that can benefit most from the intervention and in which patients these interventions are unlikely to be effective. In addition, usual care ought to be more robustly determined, reflecting best practice as defined in the current guidelines, although this is not commonly the case. Furthermore, to aid robust cost-effectiveness estimations, the costs associated with usual care and RM interventions need to be reported in detail (including the costs of HF treatment pathways) and QoL needs to be reported with observations at specific time points in order to estimate the difference in the utility of the patients between the RM and usual care groups. Future studies should provide greater detail on reconfiguration and set up costs and link more clearly with the financial impact (e.g. cost variation with scale and over time) on provider organisations. Wider adaptation of RM in the NHS can be facilitated by providing financial impact data (e.g. set up costs, quarterly costs of service, costs of reconfiguration) along with the long term cost-effectiveness information.

The results of the current analysis have important implications for the healthcare systems facing rising demand from emergency admissions. HF is a leading cause of hospitalisation in the UK, with 58,164 admissions recorded for HF (as first diagnoses) between April 2009 to March 2010 in England and Wales.[25] The cost of inpatient bed days for HF alone has been estimated at £563 million,[26] with around 90% of HF admissions to emergency departments,[27] lasting a median of nine days.[25] The evidence shows that use of RM could substantially reduce HF admissions, with an associated reduction in pressure on acute beds, and consequent cost savings. Furthermore, the use of TM might allow the potential transfer from emergency admission to elective admission i.e. scheduling admissions of patients directly (not via A&E) to either a ward or to a day unit for offloading, leading to major resource savings, with less patient disutility.

Indeed, the Department of Health (DH) recognised this potential and launched an initiative, "3 Million Lives" (3ML), to help at least three million people with long term conditions and/or social care to benefit from the use of telehealth and telecare services[28]. A concordat has been entered into by the DH and the telehealth and telecare industry to work together to accelerate the use of TM[29]. Thus far, seven pathfinder sites have agreed contracts with industry to ensure that 100,000 people benefit from technology in 2013[30]. Implemented effectively as part of a whole system redesign of care, TM may alleviate pressure on long term NHS costs and improve people's quality of life through better self-care in the home setting.

Contributors PT developed the decision analytical model, undertook the analysis and drafted the paper. HB assisted in parameter searching, model development and analysis. AB provided expert modelling advice. AP was responsible for conception and design, undertook the systematic review along with TG and provided data for the meta-analysis. JWS and JW provided meta-analysis results and statistical input. AB, AAM, JC and MRC provided expert clinical input. RW developed and undertook the literature searches. All authors commented on the draft/final paper.

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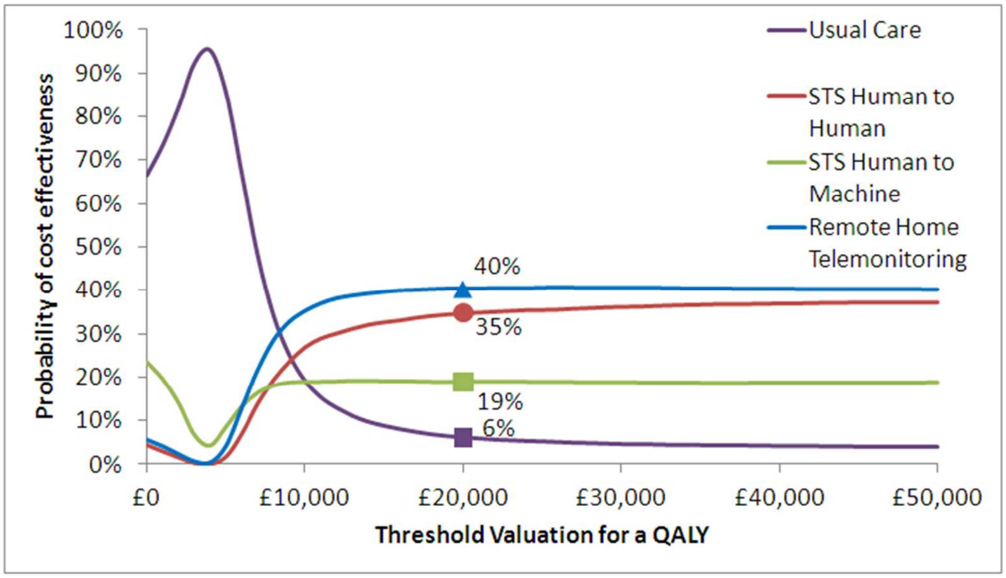

Figure 1: CEAC for basecase economic analysis using effectiveness data including Home-HF study
189x109mm (96 x 96 DPI)

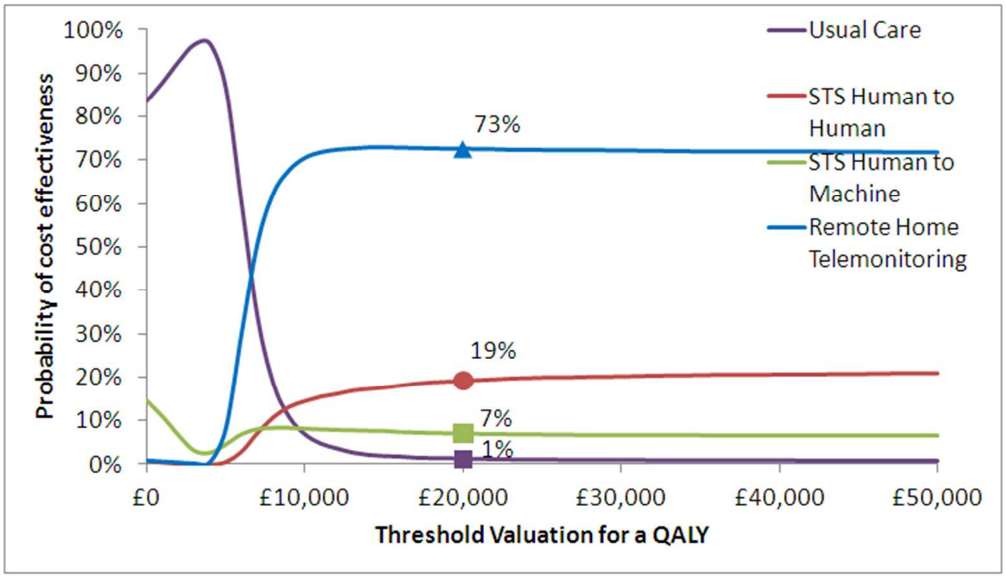

Figure 2: CEAC for economic analysis using effectiveness data excluding Home-HF study
189x109mm (96 x 96 DPI)

TELEMONITORING AFTER DISCHARGE FROM HOSPITAL WITH HEART FAILURE - COST-EFFECTIVENESS MODELLING OF ALTERNATIVE SERVICE DESIGNS

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ABSTRACT

OBJECTIVES: To estimate the cost-effectiveness of remote monitoring strategies versus usual care for adults recently discharged after a heart failure (HF) exacerbation.

DESIGN: Decision analysis modelling of cost-effectiveness using secondary data sources.

SETTING: Acute hospitals in the United Kingdom.

PATIENTS: Patients recently discharged (within 28 days) after a heart failure (HF) exacerbation

INTERVENTIONS: Structured telephone support (STS) via human to machine (STS HM) interface, b) STS via human to human (STS HH) contact, and c) home telemonitoring (TM), compared against d) usual care.

MAIN OUTCOME MEASURES: The incremental cost per quality-adjusted life year (QALY) gained by each strategy compared to the next most effective alternative and the probability of each strategy being cost-effective at varying willingness to pay per QALY gained.

RESULTS: TM was the most cost-effective strategy in the scenario using these base case costs. Compared with usual care, TM had an estimated incremental cost effectiveness ratio (ICER) of £~~9,552~~11,873/QALY, whereas STS HH had an ICER of £228,035~~£63,240~~/QALY against TM. STS HM was dominated by usual care. Threshold analysis suggested that the monthly cost of TM has to be higher than £390 to have an ICER greater than £20,000/QALY against STS HH. Scenario analyses performed using higher costs of usual care, higher costs of STS HH and lower costs of TM do not substantially change the conclusions.

CONCLUSIONS: Cost-effectiveness analyses suggest TM was an optimal strategy in most scenarios, but there is considerable uncertainty in relation to clear descriptions of the interventions and robust estimation of costs.

BACKGROUND

Heart failure (HF) is associated with high levels of morbidity and mortality, with the highest risk immediately after discharge from hospital.[1] 20-30% of patients are readmitted within 30 days, rising to 50% at six months.[2] Patients who are discharged have around 28% risk of mortality within the first year after HF discharge.[3] Strategies to slow disease progression are needed for at-risk patients, to improve the prognosis, even among those receiving optimal pharmaceutical therapy.[4]

Remote monitoring (RM) of indicators of deterioration (e.g. weight, arrhythmia, blood pressure, intrathoracic impedance, heart rates during rest and exertion, and symptom control) can facilitate early detection of clinically significant changes and thus earlier intervention to restabilise the syndrome, prevent emergency admissions, and avoid complications.[5] RM can be broadly classified into telemonitoring (TM), in which physiological data are electronically transmitted to a healthcare team, and structured telephone support (STS), that is, the use of phone calls, usually by specialist nurses, to deliver self-care support and/or management.[6,~~7~~] For STS, support can be provided by human-to-human contact (HH), or via a human-to-machine interface (HM); that is, STS with an interactive response system (e.g. a voice-interactive system). For TM, support can be provided during office hours only or 24 hours per day, seven days per week (24/7), though few studies have used the latter approach.

The cost-effectiveness of a RM strategy can be estimated by comparing the outcomes and costs associated with the strategy to the next most effective alternative. If these outcomes are estimated as quality-adjusted life years (QALYs) then the incremental cost-effectiveness ratio (ICER), or cost per QALY gained, can be calculated and compared to alternative uses of health care funding. In the United Kingdom (UK), NICE typically recommends in favour of funding interventions with an ICER below thresholds of £20,000/QALY, requires considerable clinical benefit to recommend funding interventions between £20,000 and £30,000/QALY, and recommends against funding interventions with an ICER above these thresholds. The aim of this paper is to estimate the incremental cost per QALY of RM strategies compared with usual care, so as to determine which RM strategy should be recommended according to typical NICE thresholds for cost-effectiveness.

METHODS

Model scope

A Markov model was developed using MS Excel software (Microsoft Corporation) to estimate the cost-effectiveness of remote monitoring (RM) interventions with usual care for patients discharged in the past 28 days with a HF-related hospitalisation,[7] measured as the incremental cost per QALY gained by each strategy compared with the next most effective alternative on the cost-effectiveness frontier. Cost-effectiveness results are estimated as mean values of 10,000 probabilistic sensitivity analysis (PSA) runs, with each PSA run using different estimates for the risks, hazard ratios, costs and utilities sampled from probability distributions representing uncertainty in the parameter estimates. Additionally, the probability that each strategy would be the most cost-effective was calculated at different thresholds for willingness to pay (WTP) for health gain. Cost-effectiveness acceptability curves were constructed by plotting the probability of each strategy being cost-effective against WTP threshold.

The following strategies post discharge interventions were tested in the model:

a) Usual care
b) STS HH (structured telephone support with human-to-human contact)
c) STS HM (structured telephone support with human-to-machine interface) and
d) TM (i.e. telemonitoring with transmitted data reviewed by medical staff or medical support provided during office hours)

The clinical effectiveness parameters of these three RM strategies were estimated from a network meta-analysis of the available evidence,[8] and costs were estimated using 'bottom up' costing methods. It was assumed that the interventions were provided for the six months following discharge from the hospital, as the majority of the RM trials included in the network meta-analysis used a six month follow-up duration.[8] At the end of six months all patients were assumed to receive usual care as per the NICE Clinical Guidelines for the Management of Adults with Chronic Heart Failure,[9] irrespective of whether they received intervention or post discharge usual care during the treatment period.

Model structure

In the Markov model, two different states were considered:

(a) Alive at home
(b) Dead

The Markov model used a monthly cycle length with half-cycle correction and assigned each patient with a monthly probability of death based on the time since discharge and the type of treatment. In each period, the patients that were alive were under the risk of an average number of monthly re-hospitalisations i.e. readmissions to a hospital for HF or other causes. Each patient then accrued lifetime QALYs and health care costs according to their hospitalisation and treatment status. The model used a 30 year (patient lifetime) horizon although the impact of each intervention was for the first six months after an initial discharge. Both the costs and QALYs were discounted at an annual discount rate of 3.5% and the economic perspective of the model was that of NHS in England and Wales. Repeat interventions after repeat hospitalisations were not considered in this model.

Baseline mortality and hospitalisation

The baseline monthly probabilities of death were estimated from the Candesartan in Heart failure: Assessment of Reduction in Mortality and morbidity (CHARM) study,[10] which included 7572 patients with mean age of 65.5 years followed up for 38 months, as it assessed the influence of non-fatal hospitalisation for heart failure on subsequent mortality. The data from the CHARM study[10] showed that the mortality risk was highest immediately after hospital discharge and then decreased over time, as shown in Table 1.

Table 1: Monthly mortality probability vs. time since discharge for HF patients in usual care

Time since discharge (in months)	Mortality Probability per month	Lower 95% confidence interval (CI)	Upper 95% CI
0–1	0.04622	0.03616	0.05891
1–3	0.03306	0.02644	0.04124
3–6	0.02674	0.02166	0.03306
6–12	0.02353	0.01964	0.02831
12–24	0.01866	0.01565	0.02226
>24	0.01467	0.01127	0.01911

The mean numbers of HF-related and other-cause hospitalisations (estimated as all-cause hospitalisations minus the HF-related hospitalisations) were estimated from a meta-analysis of 21 studies (5715 patients, median age 70.7 ranging from 45 to 78 years) reported by Klersy *et al.*[11] The average number of monthly HF-related and all cause re-hospitalisations for patients in usual care are as shown in Table 2.

Table 2: Monthly risk of hospitalisations per patient in usual care

	Source	Estimate	Lower 95% CI	Upper 95% CI
HF-related hospitalisations	Klersy *et al.* [11]	0.0350	0.0325	0.0375
All-cause hospitalisations	Klersy *et al.* [11]	0.0875	0.0841	0.0908

Effectiveness of interventions

The effectiveness parameters in the economic model were the hazard ratios (HRs) for all-cause mortality, all-cause hospitalisations and HF-related hospitalisations for the different interventions (i.e. STS HM, STS HM and TM) against standard care. These effectiveness parameters were estimated from a network meta-analysis (NMA) of 21 RM studies[8] (total 6317 patients, with mean age across studies ranging from 57 to 78 years) and applied to the baseline parameters to estimate the hospitalisation and mortality risk parameters for the different interventions. It was assumed that the treatment effectiveness (and costs) lasts only for the treatment duration of six months, after which the baseline risks of hospitalisation and mortality were applied.

It should be noted that considerable heterogeneity was identified in the manner in which RM and usual care were performed among the studies included in the NMA,[8] which resulted in heterogeneity between studies in the estimate of HRs. For example, in RM, there was variation between studies in the type of devices used, parameters monitored and the protocols for triage and follow-up. In particular, the data from Dar *et al*[12] (Home-HF trial conducted in three district general hospitals in West London) appeared to be inconsistent with the data from the remaining studies because it showed a higher incidence of mortality among the TM group than the usual care group. However, the 6-month mortality rate in the usual care group (5.5%) was substantially lower than would be expected in an HF cohort receiving care outside the context of a clinical trial (that is, between 13% and 21%),[3] which the authors attributed to the high quality usual care (provided by a HF nurse specialist and a consultant with an interest in HF). The impact of this study was assessed in sensitivity analyses, and HRs from both of the NMAs are presented in Table 3.

Table 3: HRs for interventions versus usual care for all-cause mortality and hospitalisations

HRs for interventions versus usual care for mortality (all-cause) and hospitalisation (all-cause and HF) from NMA including Home-HF[12] study

Type	All-cause mortality		HF-hospitalisation		All-cause hospitalisation	
	HR	95% PrI	HR	95% PrI	HR	95% PrI
STS HH	0.77	(0.31, 1.86)	0.77	(0.50, 1.19)	0.97	(0.38, 2.43)
STS HM	0.98	(0.30, 3.23)	1.03	(0.58, 1.77)	1.06	(0.31, 3.61)
TM	0.76	(0.30, 1.91)	0.95	(0.59, 1.62)	0.75	(0.28, 1.91)

HRs for interventions versus usual care for mortality (all-cause) and hospitalisation (all-cause and HF) from NMA excluding Home-HF[12] study						
STS HH	0.75	(0.45, 1.27)	0.76	(0.51, 1.13)	0.96	(0.42, 2.18)
STS HM	0.98	(0.49, 1.95)	1.02	(0.61, 1.69)	1.06	(0.35, 3.22)
TM	0.62	(0.35, 1.09)	0.86	(0.54, 1.38)	0.67	(0.26, 1.53)

HR, hazard ratio; PrI, predictive interval; STS HM, structured telephone support via human to machine interface; STS HH, structured telephone support via human to human contact; TM, telemonitoring

On deciding which of these results are most representative of their setting, the key questions for decision-makers relate to the inclusion of the Home-HF study[12] in the effectiveness meta-analyses. If one accepts that usual care is best represented by the usual care arm in the Home-HF study,[12] which is the only study showing a statistically significant difference in effectiveness of usual care over RM, then the results including Home-HF study[12] might be considered more relevant than those without. If on the other hand, one considers that the performance of usual care is better represented by the other studies and that usual care in Home-HF study[12] is not representative of current usual care, then the results excluding Home-HF study[12] might be more generalisable. This consideration predominantly affects the hazard ratios around the telemonitoring intervention only and does not impact ~~significantly~~ substantially on the structure telephone service interventions.

Health-related quality of life

A review was conducted to estimate the health-related quality of life (HRQoL) and four studies were found [13-16], all of which reported utilities for recently discharged HF patients under usual care around 0.57 to 0.6. There was no quantified evidence on the extent to which RM improves HRQoL of the patients in the RM studies included in the NMA, thus, the same utility values were used for HF patients in both usual care and (each of the three) RM strategies in the economic model. The disutility caused by re-hospitalisation for HF was estimated as 0.1 based on a study by Yao et al,[17] who estimated the disutility to be equivalent to the utility of one health state lower in terms of New York Heart Association (NYHA) class and this disutility was assumed to last for one year. In the absence of evidence regarding the disutility caused by re-hospitalisation for other causes (not directly HF-related), it was assumed that there was no disutility caused by re-hospitalisation for other causes.

A utility score of 0.58 was applied to the patients for each month in the first year after discharge and a utility of 0.67 was used after the first year. Any HF-related hospitalisation was assumed to result in a disutility of 0.1 for a whole year i.e. the utility of the patient for that year was 0.67-0.1 i.e. 0.57. Within the PSA, the uncertainty in the utility values were represented using a normal distribution using the deterministic values as mean with a standard deviation of 0.015, estimated based on the difference between utilities reported by Capomolla *et al*[13] and Iqbal *et al*,[15] while the disutility was represented using a triangular distribution with [-0.08,0.11] as the range with -0.1 as the mode.

Costs

The costs used in the model are a) costs of RM interventions after initial discharge only, b) costs of usual care and c) repeat hospitalisation costs. These costs are summarised in Table 4 and are described in detail in this section.

The RM studies did not report clearly or in detail what was involved in the usual post discharge care or RM, thus making it difficult to accurately determine the costs.[8] Due to the variation involved in the RM interventions and usual care, cost scenarios were developed for each RM classification (i.e. STS HM, STS HH and TM) and usual care. These costs were estimated using bottom-up costing methods for a typical health organisation of 250 HF patients (estimated based on median size of NHS Foundation Trusts in the UK) for a period of six months. Furthermore, it was assumed that after six months all patients would receive usual care as recommended in NICE clinical guidelines for the management of adults with CHF,[9] irrespective of whether they received the remote monitoring intervention or post discharge usual care during the intervention period.

It was assumed that the usual post discharge care was the same as that described in the TEN-HMS study[18] and the usual care costs were estimated by applying the hourly NHS staff rates from PSSRU 2011[19] to the resource use data in the TEN-HMS study.[18] A high cost usual post discharge care scenario was also developed based on discussions with the clinical expert advisory group (AB, AAM, JC and MRC).

The total costs of RM interventions were broken down into the costs of the device, monitoring costs and medical care costs.[8] The costs of the RM devices were elicited from the expert advisory group. The monitoring costs were estimated using activity-based costing for the resources spent by staff on triage and follow-up based on evidence from the literature.[20] The costs of medical care were estimated by applying the hourly NHS staff rates from PSSRU 2011[19] to the resource use data in the TEN-HMS study,[18] which reported the medical care received in the usual care arm, STS and TM arms.

The mean inpatient admission cost for HF-related hospitalisations was calculated from the weighted average of the costs for the HRG "Heart Failure or Shock" (EB03H, EB03I) based on the data obtained from the NHS Reference Costs for 2011.[21] For hospital admissions for any cause other than HF, it was assumed that these costs were the same as the mean cost of hospital admission for the general population. This was estimated as a weighted average of elective inpatient admissions and non-elective inpatient admissions (including both short and long stay) based on the data from the NHS Reference Costs for 2011.[21]

Table 4: Cost parameters used in the economic model

Costs (in £) per six months	**Base case scenario**	**Low cost scenario**	**High cost scenario**	**Source**
UC	£161	-	£592	TEN-HMS,[18] Clinical opinion
STS HM	£715	£623	£794	Clinical opinion
STS HH	£1075	£1051	£1152	Clinical opinion
TM	£1051	£801	£1288	Clinical opinion
Usual care costs (per month) after six month intervention duration				

UC after six months	£8.23	-	-	NICE HF guidelines[9]
Hospitalisation costs	**Estimate**	**Lower 95% CI**	**Upper 95% CI**	
HF-related hospitalisations[a]	£2,514.49	£1,857	£2,809	NHS Reference Costs for 2011[21]
Other-cause hospitalisations[b]	£1,529.79	£1,129	£1,709	NHS Reference Costs for 2011[21]

[a] Heart failure or shock (EB03H EB03I): Non-elective inpatient (long stay) including excess bed days[21]

[b] Non-elective inpatient (long and short stay) including excess bed days[21]

RESULTS

The results of the cost-effectiveness analysis using base case costs are presented in Table 5 for both estimates of effectiveness, including and excluding data from the Home-HF study,[12] to address the uncertainty in the effectiveness evidence. Results are also presented for five cost scenarios (higher usual care cost scenario, lower cost scenario of TM, higher cost scenario of TM, lower STS cost scenario and higher STS cost scenario) and the 12 month intervention duration scenario in supplementary Tables 1 and 2, respectively.

Table 5: Summary of the economic analysis results using base case costs

	Usual care	STS HM	STS HH	TM
Total costs				
Including Home-HF[12]	£8,478	£8,965	£9,574	£9,437
Excluding Home-HF[12]	£8,478	£9,087	£9,658	£9,665
Total QALYs				
Including Home-HF[12]	2.4137	2.3633	2.4950	2.4944
Excluding Home-HF[12]	2.4137	2.4043	2.5230	2.5847
ICERs				
Including Home-HF[12]		Dominated	£228,035[a]	£11,873
Excluding Home-HF[12]		Dominated	Extendedly dominated	£6,942[a]
Probability of cost-effectiveness				
Including Home-HF[12]	6%	19%	35%	40%
Excluding Home-HF[12]	1%	7%	19%	73%

STS HM, structured telephone support via human to machine interface; STS HH, structured telephone support via human to human contact; TM, telemonitoring; ~~UC, usual care;~~ QALYs, quality adjusted life years; ~~NB, net benefit;~~ ICERs, incremental cost-effectiveness ratios

[a] last strategy in the cost-effectiveness frontier

In the analysis using base case costs, TM is the most cost-effective strategy at a threshold of £20,000/QALY in both analyses i.e. including and excluding the Home-HF study.[12] TM is also the most effective strategy (i.e. highest QALYs gained) in the analyses that excluded the Home-HF study,[12] but not in the analyses that included Home-HF study,[12] with STS HH providing the highest number of expected QALYs. However, the additional QALYs gained by STS HH are not worth the additional costs of the strategy as seen in the ICERs (against TM) greater than the threshold of £20,000/QALY.

In the analyses that included the Home-HF study,[12] there is only a 40% chance of TM being cost-effective at the threshold of £20,000/QALY, as shown in Figure 1. Excluding the Home-HF study,[12] the probability that TM during office hours is cost-effective increases to 73% (Figure 2).

Figure 1: CEAC for basecase economic analysis using effectiveness data including Home-HF study[12]

Figure 2: CEAC for economic analysis using effectiveness data excluding Home-HF study[12]

Scenario analyses performed using higher costs of usual care, higher costs of STS HH and lower costs of TM do not substantially change the conclusions. TM was estimated to be the most cost-effective strategy in all these scenarios. Scenario analysis performed using higher costs of TM (£215 per month) suggested that TM is dominated by STS HH. This is because a small change in the difference between costs of TM and STS HH led to a marked change in ICERs, given the small difference (0.0021 QALYs) in expected QALYs between STS HH and TM in the analyses that included the Home-HF study.[12] However, the same scenario analysis (i.e. higher cost of TM of £215 per month) that excluded the data from Home-HF study,[12] suggested that TM is still the most cost-effective strategy with an ICER of £8,223~~7,854~~/QALY against usual care (STS HH is extendedly dominated by a combination of usual care and TM). This is due to the much higher difference in the expected QALYs between STS HH and TM (0.0602 QALYs), where a small change in the difference between costs of TM and STS HH can not lead to a marked change in the ICER. Threshold analysis suggested that the monthly cost of TM has to be higher than £390 per month to have an ICER greater £20,000/QALY against STS HH. The ICER of TM against usual care, at this monthly cost of £390, is £13,357/QALY.

Scenario analyses performed using different estimates of the disutility for HF-related and other cause hospitalisations produced results similar to that in the basecase analysis i.e. the results are robust to the variations in the disutility of hospitalisations.

Scenario analysis using 12 month treatment duration produced similar results as in the six month treatment duration scenarios. TM for 12 months was also cost-effective when compared against TM for six months with an ICER of £14,066~~12,213~~/QALY. However, treating 2**N* patients using TM for six months was cost-effective with ~~an ICER of £793/QALY against~~ it dominant against a combination of treating *N* patients using TM for 12 months with the rest of the *N* patients under usual care.

DISCUSSION

The results of the base case cost-effectiveness analyses suggest that TM is expected to be the most cost-effective strategy at a threshold of £20,000/QALY. However, there is uncertainty involved in suggesting that TM is the most probable cost-effective strategy and in particular, there is greater uncertainty when data from Home-HF study[12] is included than when it is excluded. For decision makers, the key question is whether the usual care in their local setting is similar to the usual care arm in the Home-HF study.[12] If so, then the results including Home-HF study[12] might be considered more relevant and if not, results excluding Home-HF study[12] might be considered more relevant. Scenario analysis performed (using higher usual care costs, lower TM costs, higher TM costs and higher STS costs) did not substantially change the conclusions, TM was estimated to be the most cost-effective strategy in all these scenarios. Furthermore, TM for 12 months was also cost-effective when compared against TM for six months, which suggests that it is cost-effective to keep the patients on TM beyond six months. In situations with a limited number of TM devices, assuming a homogenous patient group, it is cost-effective to treat all patients using TM for six months than using TM for 12 months on half the patients with the other half of the patients under usual care.

There have been two cost-effectiveness analyses studies of RM in HF, but neither considered the different RM approaches separately.[11,22] The analysis reported by Miller *et al.*[22] was based on a single trial of STS,[23] whereas Klersy *et al*[11] included data from a meta-analysis of a wide range of RM studies. Miller *et al*[22] estimated that STS compared with usual care had an ICER around $43,650 per QALY, this study did not perform a PSA, but only univariate sensitivity analyses (ICER varying from $28,691 to $129,738). Klersy *et al*[11] focused mainly on the effectiveness rather than the costs and used a time horizon of one year. A budget impact analysis was presented and the different diagnosis-related group (DRG) reimbursement tariff groups, as proxy for hospitalisations costs, were considered with cost savings per patient ranging between €306.8 and €992.94. However, other costs such as RM costs and outpatient visit costs were not considered. The authors performed scenario analyses using different DRG costs as part of the budget analysis to address the uncertainty in the hospitalisation costs, but neither deterministic sensitivity analysis nor PSA were performed.

Whole Systems Demonstrator (WSD) Programme,[24] a randomised controlled trial of telehealth that included over 6,000 patients, analysed costs and outcomes for 965 patients monitored for 12 months: 534 receiving telehealth and 431 receiving usual care. Cost-effectiveness analysis estimated the ICER £92,000/QALY when telehealth when added to usual care for people with chronic conditions (diabetes, HF, and COPD). However, this trial based evaluation (with a time horizon of 1 year) potentially underestimates the health benefits as it does not include the long-term QALYs gained from the reduction in mortality. Furthermore, the WSD analysis included all patients with chronic conditions (diabetes, HF, and COPD) whereas the population under consideration in our analysis are patients who are recently discharged with HF. The cost-effectiveness results for HF patients are not yet publically available in a peer-reviewed journal and thus, it is difficult to compare the results of the current analysis with the results of the WSD analysis.

The analysis reported in this paper also has some limitations that need to be taken into account. Any modelling process involves simplifications and assumptions that may not accurately reflect clinical practice. Due to the lack of detail provided in research studies included in the NMA concerning the components of RM packages and usual care (e.g. communication protocols, routine staff visits, and resources used), scenarios for different RM classifications were developed and their costs were estimated using bottom-up costing methods. Although the users can decide which of these analyses is most representative of their setting, uncertainties still remain about the assumptions made in the estimation of these costs. However, it should be noted that the monthly costs estimated were similar to those reported in the WSD. Implementation costs (such as set-up costs, staff training costs, service reconfiguration costs, costs for dual running of usual care and RM services) were not included in the model but are often a consideration for the health organisations.

RM interventions included in the NMA were heterogeneous in terms of monitored parameters and selection criteria for HF; this was the case even within specific types of RM (STS HH, STS HM, and TM) and is reflected in the uncertainty of the effectiveness parameters. A limitation of the analyses is that the effectiveness parameters remained the same for the different cost scenarios whereas in reality there might be some correlation between the costs and effectiveness of different RM strategies. Also, it was assumed that the effectiveness and costs of the interventions are constant over time, irrespective of the duration of deployment. Furthermore, as the analysis is not severity specific, it assumes that the interventions are equally effective in different severity groups within the population under consideration (i.e. patients who are recently discharged with HF). Repeat interventions after repeat hospital admissions for heart failure are not modelled as the model complexity would increase beyond practical analyses and the mortality risk is not reset for patients who are re-admitted as this would need detailed evidence on baseline risks and effectiveness in different patient groups. As this detailed evidence is not available, the cohort model uses evidence about the overall average of the patients to estimate the cost-effectiveness.

Some of the assumptions above may not hold true in reality and further research is needed to address these issues. Given the complex nature of RM interventions, new research should seek to examine the 'active ingredients' of RM and identify patient subgroups that can benefit most from the intervention and in which patients these interventions are unlikely to be effective. In addition, usual care ought to be more robustly determined, reflecting best practice as defined in the current guidelines, although this is not commonly the case. Furthermore, to aid robust cost-effectiveness estimations, the costs associated with usual care and RM interventions need to be reported in detail (including the costs of HF treatment pathways) and QoL needs to be reported with observations at specific time points in order to estimate the difference in the utility of the patients between the RM and usual care groups. Future studies should provide greater detail on reconfiguration and set up costs and link more clearly with the financial impact (e.g. cost variation with scale and over time) on provider organisations. Wider adaptation of RM in the NHS can be facilitated by providing financial impact data (e.g. set up costs, quarterly costs of service, costs of reconfiguration) along with the long term cost-effectiveness information.

The results of the current analysis have important implications for the healthcare systems facing rising demand from emergency admissions. HF is a leading cause of hospitalisation in the UK, with 58,164 admissions recorded for HF (as first diagnoses) between April 2009 to March 2010 in England and Wales.[25] The cost of inpatient bed days for HF alone has been estimated at £563 million,[26] with around 90% of HF admissions to emergency departments,[27] lasting a median of nine days.[25] The evidence shows that use of RM could substantially reduce HF admissions, with an associated reduction in pressure on acute beds, and consequent cost savings. Furthermore, the use of TM might allows the potential transfer from emergency admission to elective admission i.e. scheduling admissions of patients directly (not via A&E) to either a ward or to a day unit for offloading, leading to major resource savings, with less patient disutility.

Indeed, the Department of Health (DH) recognised this potential and launched an initiative, "3 Million Lives" (3ML), to help at least three million people with long term conditions and/or social care to benefit from the use of telehealth and telecare services[28]. A concordat has been entered into by the DH and the telehealth and telecare industry to work together to accelerate the use of TM[29]. Thus far, seven pathfinder sites have agreed contracts with industry to ensure that 100,000 people benefit from technology in 2013[30]. Implemented effectively as part of a whole system redesign of care, TM ~~can~~ may alleviate pressure on long term NHS costs and improve people's quality of life through better self-care in the home setting.

Contributors PT developed the decision analytical model, undertook the analysis and drafted the paper. HB assisted in parameter searching, model development and analysis. AB provided expert modelling advice. AP was responsible for conception and design, undertook the systematic review along with TG and provided data for the meta-analysis. JWS and JW provided meta-analysis results and statistical input. AB, AAM, JC and MRC provided expert clinical input. RW developed and undertook the literature searches. All authors commented on the draft/final paper.

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Supplementary Table 1: Summary of the economic analysis results for different scenarios

Higher usual care cost (£98.7 per patient per month) scenario				
	Usual care	**STS HM**	**STS HH**	**TM**
Total costs				
Including Home-HF[12]	£8,861	£8,965	£9,574	£9,437
Excluding Home-HF[12]	£8,861	£9,087	£9,658	£9,665
Total QALYs				
Including Home-HF[12]	2.4137	2.3633	2.4950	2.4944
Excluding Home-HF[12]	2.4137	2.4043	2.5230	2.5847
ICERs				
Including Home-HF[12]		Dominated	£228,035[a]	£7,133
Excluding Home-HF[12]		Dominated	Extendedly dominated	£4,703[a]
Probability of cost-effectiveness				
Including Home-HF[12]	4%	19%	35%	41%
Excluding Home-HF[12]	1%	7%	19%	73%

Lower cost (£133.5 per patient per month) of TM during office hours scenario				
	Usual care	**STS HM**	**STS HH**	**TM**
Total costs				
Including Home-HF[12]	£8,478	£8,965	£9,574	£9,211
Excluding Home-HF[12]	£8,478	£9,087	£9,658	£9,435
Total QALYs				
Including Home-HF[12]	2.4137	2.3633	2.4950	2.4944
Excluding Home-HF[12]	2.4137	2.4043	2.5230	2.5847
ICERs				
Including Home-HF[12]		Dominated	£605,112[a]	£9,080
Excluding Home-HF[12]		Dominated	Extendedly dominated	£5,595[a]
Probability of cost-effectiveness				
Including Home-HF[12]	6%	18%	33%	44%
Excluding Home-HF[12]	1%	6%	16%	77%

STS HM, structured telephone support via human to machine interface; STS HH, structured telephone support via human to human contact; TM, telemonitoring; QALYs, quality adjusted life years; ICERs, incremental cost-effectiveness ratios

[a] last strategy in the cost-effectiveness frontier

Higher cost (£215 per patient per month) of TM during office hours scenario				
	Usual care	**STS HM**	**STS HH**	**TM**
Total costs				
Including Home-HF[12]	£8,478	£8,965	£9,574	£9,652
Excluding Home-HF[12]	£8,478	£9,087	£9,658	£9,884
Total QALYs				
Including Home-HF[12]	2.4137	2.3633	2.4950	2.4944
Excluding Home-HF[12]	2.4137	2.4043	2.5230	2.5847
ICERs				
Including Home-HF[12]		Dominated	£13,473[a]	Dominated
Excluding Home-HF[12]		Dominated	Extendedly dominated	£8,223[a]
Probability of cost-effectiveness				
Including Home-HF[12]	7%	20%	37%	37%
Excluding Home-HF[12]	1%	8%	23%	68%

Higher cost (£192 per patient per month) of STS HH scenario				
	Usual care	**STS HM**	**STS HH**	**TM**
Total costs				
Including Home-HF[12]	£8,478	£8,965	£9,645	£9,437
Excluding Home-HF[12]	£8,478	£9,087	£9,729	£9,665
Total QALYs				
Including Home-HF[12]	2.4137	2.3633	2.4950	2.4944
Excluding Home-HF[12]	2.4137	2.4043	2.5230	2.5847
ICERs				
Including Home-HF[12]		Dominated	£346,341[a]	£11,873
Excluding Home-HF[12]		Dominated	Extendedly dominated	£6,942[a]
Probability of cost-effectiveness				
Including Home-HF[12]	6%	19%	34%	41%
Excluding Home-HF[12]	1%	7%	18%	74%

STS HM, structured telephone support via human to machine interface; STS HH, structured telephone support via human to human contact; TM, telemonitoring; QALYs, quality adjusted life years; ICERs, incremental cost-effectiveness ratios

[a] last strategy in the cost-effectiveness frontier

Lower cost (£175 per patient per month) of STS HH scenario				
	Usual care	**STS HM**	**STS HH**	**TM**
Total costs				
Including Home-HF[12]	£8,478	£8,965	£9,553	£9,437
Excluding Home-HF[12]	£8,478	£9,087	£9,636	£9,665
Total QALYs				
Including Home-HF[12]	2.4137	2.3633	2.4950	2.4944
Excluding Home-HF[12]	2.4137	2.4043	2.5230	2.5847
ICERs				
Including Home-HF[12]		Dominated	£193,206[a]	£11,873
Excluding Home-HF[12]		Dominated	Extendedly dominated	£6,942[a]
Probability of cost-effectiveness				
Including Home-HF[12]	6%	19%	35%	40%
Excluding Home-HF[12]	1%	7%	20%	72%

STS HM, structured telephone support via human to machine interface; STS HH, structured telephone support via human to human contact; TM, telemonitoring; QALYs, quality adjusted life years; ICERs, incremental cost-effectiveness ratios

[a] last strategy in the cost-effectiveness frontier

Supplementary Table 2: Results for 12 month treatment duration scenarios

Summary of the economic analysis results using 12 month treatment duration

	Usual care	STS HM	STS HH	TM
Total costs				
Including Home-HF[12]	£8,562	£9,564	£10,582	£10,326
Excluding Home-HF[12]	£8,562	£9,708	£10,707	£10,698
Total QALYs				
Including Home-HF[12]	2.4137	2.3536	2.5589	2.5576
Excluding Home-HF[12]	2.4137	2.4044	2.6005	2.7065
ICERs				
Including Home-HF[12]		Dominated	£205,812[a]	£12,257
Excluding Home-HF[12]		Dominated	Extendedly dominated	£7,296[a]
Probability of cost-effectiveness				
Including Home-HF[12]	7%	19%	34%	40%
Excluding Home-HF[12]	1%	7%	19%	73%

STS HM, structured telephone support via human to machine interface; STS HH, structured telephone support via human to human contact; TM, telemonitoring; UC, usual care; QALYs, quality adjusted life years; NB, net benefit; ICERs, incremental cost-effectiveness ratios

[a] last strategy in the cost-effectiveness frontier

Cost-effectiveness of TM during office hours for 12 months vs. TM during office hours for 6 months

	TM during office hours for 6 months		TM during office hours for 12 months		ICER (TM for 12 months vs. TM for 6 months)
	Costs	QALYs	Costs	QALYs	
Including Home-HF[12]	£9,437	2.4944	£10,326	2.5576	£14,066/QALY
Excluding Home-HF[12]	£9,665	2.5847	£10,698	2.7065	£8,481/QALY

TM, telemonitoring; UC, usual care; QALYs, quality adjusted life years; ICERs, incremental cost-effectiveness ratios

Cost-effectiveness of TM during office hours for 12 months vs. TM during office hours for 6 months in situations with a limited number of TM devices

	N patients on TM during office hours for 12 months and *N* patients on usual care[a]		*2*N* patients on TM during office hours for 6 months		ICER (TM for 12 months vs. TM for 6 months)
	Costs	QALYs	Costs	QALYs	
Including Home-HF[12]	£18,888	4.9713	£18,874	4.9888	Dominant
Excluding Home-HF[12]	£19,260	5.1202	£19,330	5.1694	£1,423/QALY

TM, telemonitoring; UC, usual care; QALYs, quality adjusted life years; ICERs, incremental cost-effectiveness ratios