An exploratory cost-effectiveness analysis of the connected health intervention to improve care for people with dementia: A simulation analysis

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Dowd, W.N., Cowell, A.J., Regan, D., Moran, K., Slevin, P., Doyle, G., Bray, J.W. An exploratory cost-effectiveness analysis of the connected health intervention to improve care for people with dementia: A simulation analysis. *Health Services and Outcomes Research Methodology* **18,** 47–62 (2018). https://doi.org/10.1007/s10742-017-0175-y

Abstract:

Many people with dementia live in the community; thus, supporting informal caregivers is critical. The Connected Health intervention facilitates collection and sharing of patient data among informal caregivers and providers to identify emerging patient needs and support rapid decision-making. This study estimates the costs of care of dementia using time-driven activity based costing of an exemplar patient. Intervention costs and health utility values were derived from a feasibility study of the intervention. A Markov model produced estimates of the cost-effectiveness of the intervention under four scenarios: (1) a minimal effect of the intervention on disease progression; (2) moderate effects on disease progression, and minimal effects on quality of life (QOL) and cost; (3) minimal effects on disease progression and QOL, and a moderate effect on cost; (4) moderate effects on disease progression and cost, with minimal effects on QOL. Cost estimates of formal and informal care ranged from €3713 to €7614 per month. Intervention costs were €484 per month. Under scenarios 2, 3 and 4, the cost per quality-adjusted life year of the intervention falls below €45,000, the threshold below which the Health Information and Quality Authority in Ireland generally accepts interventions as cost-effective. The results suggest that the intervention would be cost-effective with limited reductions in rates of disease progression and cost of care, and with minimal improvements in quality of life. Future research should consider the specific experiences of intervention patients.

Keywords: cost | cost-effectiveness | dementia | informal care

Article:

Introduction

Dementia is a progressive mental disease marked by diminishing memory, orientation, learning capacity, and general cognitive functioning. Around the world, 46 million people are affected by the disease, and the estimated global societal cost of dementia exceeded $800 billion in 2015 (Prince et al. 2015). Much of the cost associated with caring for people with dementia is borne

by family and friends who provide informal care, placing a considerable burden on these informal caregivers. In 2015, informal care costs totaled $330.8 billion, over 40% of the total (Prince et al. 2015).

There are economic and social advantages to providing care for people with dementia in the community. A recent study in eight European countries found that costs of dementia care in a homecare setting were significantly lower than in institutional long-term care (LTC) settings (Wübker et al. 2015). Additionally, a recent review found that people with dementia in homecare experienced higher quality of life than did those in institutional settings (Jing et al. 2016), and high levels of caregiver burden have been shown to have a negative impact on both caregiver and patient health, and often lead to expedited placement in LTC (Etters et al. 2008; Gaugler et al. 2009). For these reasons, identifying ways to support informal caregivers of people with dementia is of paramount importance.

Approximately 41,500 people live with dementia in Ireland, and this figure is estimated to triple by 2041 (Cahill et al. 2012a, b; Connolly et al. 2014). Nearly 63% of individuals living with dementia in Ireland live in the community, or outside residential LTC and other healthcare settings (Connolly et al. 2014). The opportunity cost of providing informal care makes up 48% of the annual cost of €1.69 billion to care for people with dementia in Ireland. The remaining costs incurred are for residential LTC services (43%), and formal health & social care (9%) (Connolly et al. 2014).

Recognizing the need to better support informal caregivers of patients with dementia in Ireland, the researchers developed a Connected Health (CH) intervention. The intervention was designed to improve informal care for people with mild or moderate dementia in the community by providing equipment and support to informal caregivers to facilitate the systematic collection and sharing of patient health data with the patient's medical providers through a secure portal. Real-time data collected in the home by caregivers allow clinicians to identify care needs and respond more quickly to potential health concerns. Increased awareness and responsiveness of medical providers to a patient's needs may improve patient outcomes and reduce caregiver burden. We conducted a feasibility study of the CH intervention to test the functionality of the intervention with 28 patients with mild dementia living in the community and to estimate the costs of a broader implementation of the intervention. During the feasibility study, costs of the intervention were measured but patient outcomes were not due to the short duration of the study.

In this paper, we describe the experience of a typical Irish patient with dementia as he/she transitions through the stages of dementia. We estimate the costs of care associated with each stage of the disease. We then develop a Markov model to demonstrate the potential impact of the intervention on the typical progression of dementia and estimate the cost-effectiveness of the intervention under four hypothetical scenarios of the intervention's impact: (1) a minimal effect of the intervention on disease progression with no effect on quality of life (QOL) or cost of care; (2) moderate effects on disease progression, and minimal effects on QOL and cost; (3) minimal effects on disease progression and QOL, and a moderate effect on cost; (4) moderate effects on disease progression and cost, with minimal effects on QOL. Given the exploratory nature of the current study, we discuss an agenda for future research on the potential for CH and similar interventions.

Methods

Overview

The perspective of the current study includes formal and informal care costs, the latter of which would be excluded from the perspective of the publicly funded health and social care system that is recommended by the Health Information and Quality Authority (HIQA) guidelines. We use a broader perspective for two reasons. First, one of the primary goals of the intervention is to reduce caregiver burden, so excluding it would be incomplete. Because caregiver time and expense is a resource and would be a major barrier to implementing any dementia intervention, it should be considered in analyses seeking to inform decision-making. Second, given our hypothesized impacts of the intervention, aggregate informal costs are greater under the intervention because of assumed delays in disease progression. Therefore, the broader perspective provides the more conservative estimate of the cost-effectiveness of the intervention.

The research team used three main approaches to estimate the cost and cost-effectiveness of the intervention. First, we employed a vignette approach as the basis for cost estimation and transition through the stages of dementia. Vignettes have been used in health services research for many years (Veloski et al. 2005), and their applications have included cost studies (Busse et al. 2008). Second, we conducted a feasibility study of the intervention to assess its functionality and cost as a fully implemented care model. The feasibility study provided an estimate of the cost to deliver the intervention and was a source of data on patients with mild dementia who would be candidates for CH participation. However, the feasibility study was time-limited and did not track these patients' disease progression. Third, we combined estimates derived from the vignette and data gathered from the feasibility study into a Markov model designed to represent patients' transition through the stages of dementia. We used the model to estimate cost effectiveness of the intervention by comparing the standard of care to four scenarios, each of which represented hypothesized impacts of the intervention on the rate of disease progression, cost of care, and quality of life. Because impact of the intervention was beyond the scope of the feasibility study, we developed hypothetical scenarios to represent possible impacts of the intervention.

Cost of Dementia Care

The vignette used to estimate the cost of care was designed to represent the progression of an exemplar patient, dubbed "Mary" through the stages of dementia as defined by the mini-mental state examination (MMSE), an 11-item questionnaire used to measure cognitive impairment in dementia patients (Perneczky et al. 2006). Mary was diagnosed with mild dementia at age 80 and continued to live in the community. She progressed through the four disease states described in Fig. 1. Specifically, she resided in the mild stage of dementia for approximately 6 months before transitioning to the moderate stage. She remained in the moderate stage for 12 months before transitioning to the moderate-severe stage for 6 months. Finally, after 24 months, Mary transitioned to the final, severe stage and entered LTC. Although we chose the name "Mary" to represent our vignette, the activities from which we computed standard of care costs are gender-neutral. Consultation with medical experts confirmed that Mary is representative of older

dementia patients (i.e., 80+ years of age) who represent a majority of dementia cases in Ireland (Connolly et al. 2014).

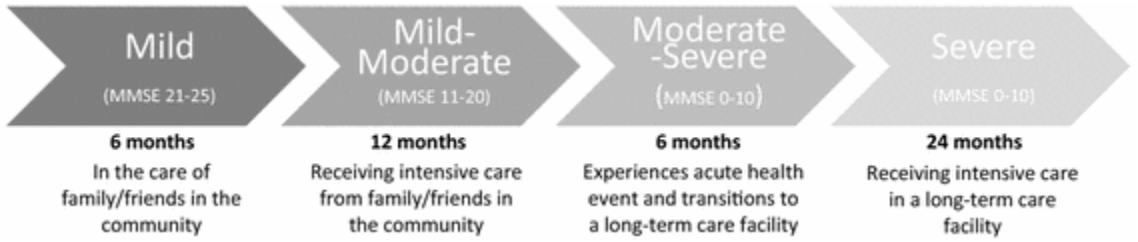

Fig. 1. Health states of dementia. *MMSE* mini-mental state examination

We gathered details of care at each stage, including procedures and costs, from interviews with providers and other staff at the participating hospitals and in the surrounding communities. We conducted semi-structured interviews (N = 105) with providers and administrators at Mater Misericordiae University Hospital and St. Vincent's University Hospital in Dublin and with health care workers in the surrounding catchment areas to gather data to estimate costs of care for the stages of dementia represented in the vignettes. Of the 105 total interviews, most (N = 75) took place among hospital staff. Nurses represented the biggest individual block (N = 25), most at a senior level within a number of different departments (i.e., emergency, care for the elderly, etc.). Doctors—from junior doctors, to consultants—were the next biggest individual block (N = 11). A large number of interviews (N = 35) were conducted among allied healthcare professionals (e.g., physiotherapists, occupational therapists, medical social workers), administrative staff (e.g., receptionists, porters, management) and laboratory staff (e.g., radiology and hematology) in hospitals. Community professionals, including general practitioners, pharmacists, public health nurses, and nursing home staff represented the remaining interviews (N = 30). We presented the vignette to each interview participant. After the respondent read the vignette, we asked the respondent to describe the care they provide for this type of patient. We asked the respondent to articulate: (1) the specific activities undertaken within this care, and (2) the duration of these activities. In addition to interviews, we conducted field observations to gather more detail about the duration of these activities.

We obtained estimates of provider salaries from publicly available health and social care system data from Health Service Executive, the Irish health service authority, in 2013. We assigned salaries from the mid-point of the salary scale (e.g., level 5 in 9-point salary scale etc.). Specific and accurate overhead cost data were provided by the finance/costing departments at the two hospital sites.

We used this information to estimate a monthly cost of care under the standard of care for each of the four disease states using a time-driven activity based costing approach (TDABC) (Kaplan and Porter 2011). We characterized the process of care with a map of activities associated with each disease state. The activities were organized around the four key locations where care is provided to dementia patients in Ireland: community-based formal care (e.g., general practitioners), hospital-based formal care, homecare (e.g., informal caregivers), and nursing home care (e.g., LTC). Cost estimates associated with each activity were derived by combining timing estimates (gathered through field observations and semi-structured interviews) and the costs of each resource (e.g., salaries and overhead). We estimated the cost of informal care using

an opportunity cost approach, which places the cost of a resource at the value of its best alternative use (Drummond et al. 2005). We assumed a value of €10 per hour for informal care (Connolly et al. 2014).

Connected Health Feasibility Study

The research team conducted a feasibility study with 28 patients with mild dementia to assess the feasibility of the intervention at a larger scale. The mean duration of the study was 6.6 weeks (range 4–9 weeks). Potential participants underwent a comprehensive health assessment in their local hospitals prior to intervention deployment, and were excluded if they had been in hospital in the previous 3 months or if they had a life expectancy of less than 6 months. The characteristics of these patients are described in Table 1.

Table 1. Connected Health feasibility study participants

Characteristics	Value
N	28
Age (mean, range)	79 (67–89)
Gender	
Female	16 (57.1%)
Male	12 (42.9%)
Marital status	
Married	17 (60.7%)
Partner	1 (3.6%)
Widowed	10 (35.7%)

Table displays frequencies with proportions in parentheses unless otherwise noted

During the feasibility study of the intervention, we identified the resources required to implement the intervention and the cost of those resources. Each participating patient received a tablet computer, a blood pressure monitor, a pulse monitor, an electronic weighing scale, and a pedometer to measure his or her daily health status. Caregivers were trained on the use of the equipment when it was first deployed to the home. The patients' general practitioners and geriatric care team had access to the health information gathered using these devices through a secure, online portal. Patients and caregivers also participated in a fortnightly tele/video consultation with the geriatric team to assess the health status of the patient. Based on resources used for the feasibility study, we estimated that the per-patient cost of the intervention was €484 per month. This includes labor costs for project management, systems engineering, and nursing staff, as well as the costs of the equipment described above, but excludes costs of resources deemed to have a purely research-oriented purpose. Labor costs were converted from the 6-week time period of the feasibility study to a monthly cost. Equipment was assumed to last 18 months, so the monthly equipment cost was equal to the total divided by 18. The costs of these resources are described in Table 2.

During the feasibility study, we collected demographic and socioeconomic data on participating patients and caregivers. A subset of patients (N = 12) completed the dementia quality of life (DEMQOL) instrument (Smith et al. 2005). We estimated quality of life for the sample of the feasibility study participants who completed the DEMQOL instrument prior to their exposure to the intervention by mapping their answers on the DEMQOL to health utility values (Rowen et

al. 2012). We relied on the DEMQOL, rather than a generic measure such as the EQ-5D, because the latter has been shown to be inappropriate for people with dementia (Rowen et al. 2012). Health utility values range from 0 to 1 and are used to calculate quality-adjusted life years (QALYs), which is a standard measure of health used in the allocation of healthcare resources (Briggs et al. 2006). Because the patients in the feasibility study had mild dementia, we assigned their average health utility value (0.90) as the value for the mild disease state.

Table 2. Components of Connected Health intervention costs

Component	**Monthly cost (€)**
Labor [a]	
Project manager (1.0 FTE)	5000
Systems engineer (1.0 FTE)	5000
Nursing staff (0.55 FTE)	2860
Equipment [b]	
Tablet	367
Scale	128
Blood pressure monitor	84
Pulse monitor	128
Total	13,567
Total per participant (n = 28)	484

[a] Salaries reflect the median of the range for individuals with these job titles and include compulsory pension and social insurance contributions

[b] Total equipment costs divided by 18 to reflect the typical patient's participation in the intervention based on the vignette

Modeling Approach

We developed a Markov model to represent the progression of our exemplar patient, Mary, through the stages of dementia over a 4 year time period (the duration of Mary's vignette). The model assumes the four disease states are sequential, no stage can be skipped, and the sequence is irreversible. Patients in any state have a probability to transition directly to the death state, which has 0 health utility and 0 cost of care. As the intervention is intended for individuals diagnosed with mild dementia, the entire cohort resides in that state prior to the first cycle.

We derived transition probabilities for the standard of care from Mary's vignette described above by assuming that the durations she spent in each state represents the median experience for patients like Mary. Probabilities of remaining in the mild, mild-moderate, and moderate-severe states were calculated as $p = 0.5^{\left(\frac{1}{N}\right)} \times (1 - d)$, where N is the number of months that the median patient will stay in that state and d is the monthly mortality rate derived from national mortality rates from the Central Statistics Office (Central Statistics Office 2009). The probability of transition to the next stage of dementia was $(1 - (p + d))$. The quantity $\frac{p}{(1-d)}$ is the probability for which the median of the geometric distribution is N. The probability of remaining in the severe state was calculated as $p = 0.5^{\left(\frac{1}{N}\right)}$ and the probability of death in that state was the quantity $(1 - p)$.

Monthly costs of care were calculated based on the interviews and field observations guided by the vignette. Costs of the intervention were added to the costs of the mild and moderate disease states. Health utility values were estimated based on the calculated utility value for those in the mild state (0.90) and zero, the assumed value for death (Drummond et al. 2005). We assumed health utility declined linearly from the mild disease state through death. Thus, we assigned a value of 0.68 to the mild-moderate state, 0.45 to the moderate-severe state, and so on.

Figure 2 describes the Markov model, complete with estimated transition probabilities for individuals receiving the standard of care. Transitions not explicitly shown are assumed to be impossible (i.e., zero probability).

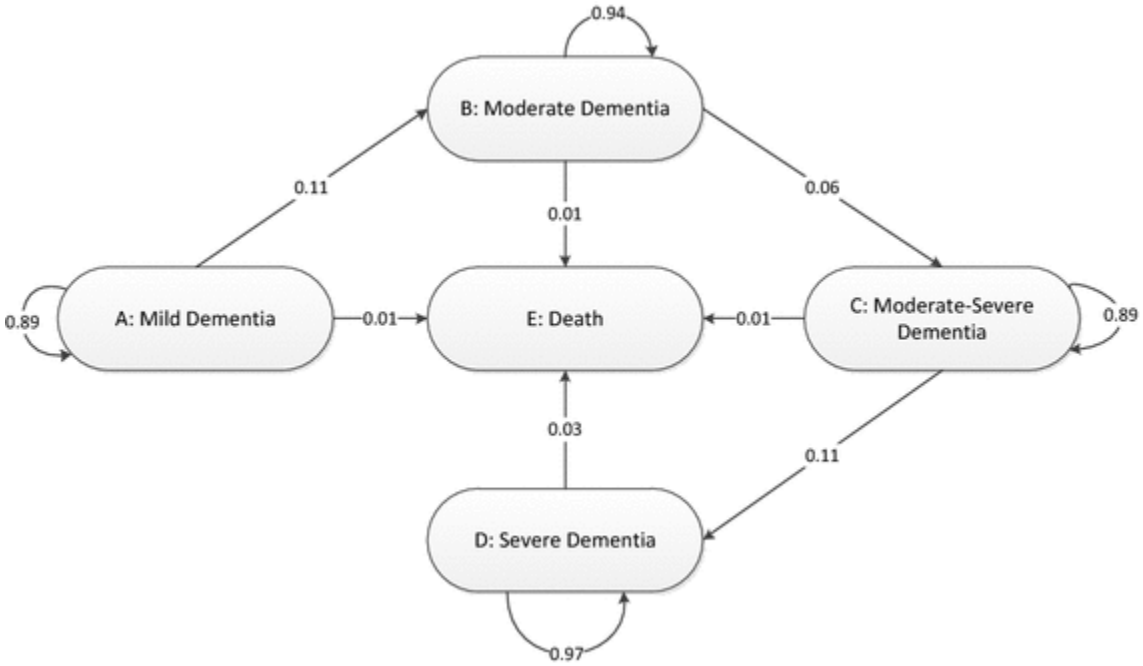

Fig. 2. Conceptual diagram of the standard of care. This diagram illustrates the movement of patients with dementia through the prototype model. They begin in with a diagnosis of mild dementia and move sequentially through the other health states based on the transition probabilities shown in the figure. Probabilities of remaining in states A, B and C are calculated as $p = 0.5^{(1/N)} \times (1 - d)$, where N is the number of months that the median patient will stay in that state and d is the monthly mortality rate (and thus, the probability of transitioning to the death state) calculated using data from the Irish Central Statistics Office (Central Statistics Office 2009). Probabilities of transition out of a given state are (1 − p). The quantity, p/(1 − d), is the probability for which the median of the geometric distribution is N. The probability of remaining in state D is calculated as $p = 0.5^{(1/N)}$. The quantity (1 − p) is the probability of death from this state

We computed costs and QALYs based on the Markov trace, which is a function of the transition probabilities and describes the proportion of patients in each disease state at each time cycle. To account for time preference (Drummond et al. 2005), we applied a 5% annual discount rate to both costs and QALYs (Health Information and Quality Authority 2014). We compared the costs and QALYs from each of the four CH scenarios to those from the standard of care condition and

estimated the incremental cost per QALY for each scenario. One can interpret the incremental cost per QALY in the context of HIQA guidelines, which suggest that the threshold for cost-effectiveness historically ranges between €20,000 and €45,000 (Health Information and Quality Authority 2014). We developed the model using Microsoft Excel.

Hypothesized scenarios

We developed four model scenarios to demonstrate how the cost-effectiveness of the intervention varies with assumptions about the degree to which the intervention slows disease progression, reduces cost of care, and improves the quality of life relative to the standard of care. Table 3 summarizes the different parameter values under each scenario. Under scenario 1, we assumed a small impact of the intervention on disease progression in the early stages of dementia, such that a typical CH patient spends 7 months in the mild state (rather than 6 months under standard of care) and 13 months in the moderate state (rather than 12 months under standard of care). Only the mild and moderate disease states are affected because the intervention is only intended to be delivered in these states. We assumed no effect on cost of care or health utility values.

Table 3. Parameters for conjectured scenarios

	Median patient duration in state (months)	Monthly probability of transition to next state	Total monthly cost[a]	Utility value
Standard of care				
Mild	6	0.11	€3713	0.90
Moderate	12	0.06	€6083	0.68
Scenario 1				
Mild	7	0.09	€4197	Same as standard of care
Moderate	13	0.05	€6567	Same as standard of care
Scenario 2				
Mild	8	0.08	€4132	0.93
Moderate	14	0.05	€6437	0.70
Scenario 3				
Mild	7	0.09	€4068	0.93
Moderate	13	0.05	€6307	0.70
Scenario 4				
Mild	8	0.08	€4068	0.93
Moderate	14	0.05	€6307	0.70

[a] Includes both cost of care and cost of the intervention, when applicable

Under scenario 2, we assumed that the intervention (a) further slows disease progression relative to scenario 1, (b) reduces cost of care, and (c) improves quality of life. (a) The intervention slows disease progression under this scenario so that the patient spends approximately 8 months in mild state (rather than 7 and 6 months under Scenario 1 and standard of care) and 14 months in moderate state (rather than 13 and 12 months under Scenario 1 and standard of care). (b) More efficient use of health care (e.g., less reliance on specialty care in the early stages of dementia) and/or delivery of care (e.g., automating documentation tasks) reduces cost of formal care by 5%. (c) During the early stages of dementia in this scenario, patients in the intervention condition have a higher quality of life than in the standard of care, in part because of reduced caregiver stress. Specifically, CH patients have health utility values that are 0.025 higher in the mild and

moderate states of dementia. In terms of utilities as measured by the DEMQOL, such a change is equivalent to a patient reporting being cheerful "a lot" rather than "quite a bit" (Rowen et al. 2012).

Under scenario 3, we assumed the minimal impact of the intervention to slow the progress of the disease from scenario 1; the minimal impact of the intervention on quality of life from scenario 2; and a larger reduction in the cost of care. In this scenario, the intervention reduces cost of formal care by 10% by the aforementioned cost reductions and efficiency gains, compared to 5% in scenario 2. In scenario 4, we combined the larger impact on disease progression from scenario 2 with the larger reduction in cost from scenario 3. We assumed the same impact on quality of life as scenarios 2 and 3.

Sensitivity Analysis

To test the sensitivity of our results to alternative rates of disease progression, we re-estimated scenarios 1 and 4 from Table 3 using transition probabilities derived from a prior study on Alzheimer's disease progression rates in the United States (Spackman et al. 2012). The authors observed few patients passing through multiple states in a year, which implies that even fewer, if any, patients transitioned by multiple states in a month, so we maintained our assumption that patients cannot progress by more than one state in a single month in the sensitivity analysis. Similarly, the authors found that few patients reverted to a less severe state, so we maintain the assumption of one-way transitions from our original model. We converted the annual transition probabilities reported in the study to monthly transition probabilities by taking the root of the matrix using a publicly available tool (Chhatwal et al. 2016) and modified the output matrix to impose the restrictions described above.

The data analyzed by Spackman et al. (2012) are characterized by a slower disease progression relative to the vignette used for this study. For example, while the vignette suggests that patients remain in the mild stage for 6 months, the authors found that patients spend on average about 28 months in the mild state. Spackman and colleagues also observe different probabilities of death from each stage of dementia, ranging from 6% per year in the mild stage to 48% per year in the severe stage. Because disease progresses slower under the sensitivity analysis scenarios, it takes a longer time to achieve a given change in state, and so we extended the analytic period from 4 years to ten. "Appendix" details the sensitivity analysis further.

Results

Costs of care associated with each disease state are presented in Table 4. The values in the table represent the costs of providing the standard of care to a dementia patient in a given state for 1 month. Formal costs of care are presented alone and combined with the costs of informal care estimated using the opportunity cost approach. As shown in the table, costs attributable to informal care make up more than half of total costs in the first two disease states when the intervention is employed.

Results under each of the hypothesized scenarios are presented in Table 5. Under the standard of care, the average patient incurs formal and informal healthcare costs equal to €204,941, and

QALYs sum to 1.60 over the course of 4 years. Under scenario 1, we estimate that CH patients would incur, on average, additional costs of €7786 relative to the standard of care over 4 years. Although the average CH patient under these assumptions enjoys an additional 0.07 QALYs over the same time period, the resulting incremental cost per QALY of €110,930 is high by HIQA standards.

Table 4. Standard of care monthly cost estimates

	Formal only	Formal cost plus opportunity cost of informal care	Percentage of costs attributable to informal care (%)
Mild	€1289.36	€3712.51	65.3
Moderate	€2603.59	€6082.72	57.2
Moderate-severe	€3859.94	€6808.34	43.3
Severe	€7614.44	€7614.44	0
Death	€0.00	€0.00	–

Table 5. Results under four conjectured scenarios

	Per-patient costs over 4 years	Cost relative to standard of care	Per-patient QALYs over 4 years	QALYs relative to standard of care	Incremental cost per QALY
Standard of care	€204,941	N/A	1.60	N/A	N/A
CH scenario 1	€212,727	€7786	1.67	0.07	€110,930
CH scenario 2	€208,525	€3584	1.79	0.19	€18,974[a]
CH scenario 3	€208,386	€3445	1.72	0.11	€30,320[a]
CH scenario 4	€206,249	€1309	1.79	0.19	€6,927[a]

We calculated Costs and QALYs for each model cycle by multiplying the probability of being in a given state by the cost and utility, respectively, associated with that state. We added these values across the 4-year period and applied a 5% annual discount rate to costs and QALYs to produce the estimates in the table. For each hypothetical scenario, the incremental cost per QALY is calculated as the difference in cost between CH and the standard of care (column 2) divided by the difference in QALYs (column 4)

CH Connected Health, *QALY* quality-adjusted life year

[a] Within HIQA cost per QALY threshold (Health Information and Quality Authority 2014)

In the remaining scenarios, the incremental cost per QALY is closer to the range often considered cost-effective. As a result of assumed delays in disease progression and reductions in cost of care, the additional costs incurred by the average CH patient relative to the standard of care falls from €7785 under the assumptions in scenario 1 to as low as €1309 in scenario 4. Additionally, due to hypothesized delays in disease progression and increases in quality of life in CH patients with mild or moderate dementia, the QALYs gained by the average CH patient increase from 0.07 in scenario 1 to as high as 0.19 in scenarios 2 and 4. This results in incremental costs per QALY of €18,974, €30,320, and €6927 for scenarios 2, 3, and 4, respectively.

Using empirical estimates of transition probabilities from the literature (Spackman et al. 2012), we estimate incremental costs per QALY of €273,272 under scenario 1 and €66,941 under scenario 4 after 10 years. Under scenario 4, the ratio of costs to QALYs gained is roughly similar after 4 years (incremental cost per QALY of €76,820), suggesting that costs and benefits of the intervention accrue at similar rates over time. Detailed output from the sensitivity analysis is available in “Appendix”.

Discussion

Given the high and increasing cost of caring for dementia patients (Cahill et al. 2012a, b; Connolly et al. 2014; Prince et al. 2015), creative and cost-effective mechanisms are needed to care for dementia patients. The study intervention, Connected Health, is designed to facilitate the rapid sharing of health data between caregivers and clinical providers, and thus has the potential to improve the efficiency of health care utilization and reduce costs. The intervention may also address the concern that many caregivers of people with dementia report inadequate support from medical providers (Jennings et al. 2015).

Presenting estimates under feasible scenarios helps to illustrate the potential impact of a fully deployed intervention under relatively modest estimates of its impact. Our findings suggest that, if the intervention can delay the typical progression of dementia into the moderate and moderate-severe states for 1 or 2 months, and if the intervention can bring about a modest improvement of the patient's quality of life, then the intervention would be considered cost-effective under commonly accepted willingness-to-pay thresholds. However, the sensitivity analysis suggests that the cost-effectiveness of the intervention is sensitive to overall rates of disease progression. The intervention would require larger impacts on disease progression, cost, and quality of life to be considered cost-effective under the rates of disease progression represented by the data used in the sensitivity analysis.

Although the feasibility study did not allow us to test the impact of the intervention on disease progression, cost, or quality of life, there is some evidence that interventions can in fact delay disease progression and increase quality of life. Studies have shown that interventions designed to reduce caregiver burden can delay nursing home placement (Andrén and Elmståhl 2008; Mittelman et al. 2006), and quality of life outcomes have been shown to be inversely related to measures of caregiver stress (Burgener and Twigg 2002). Furthermore, our analysis does not consider the impact on patients' caregivers who are at risk for physical and mental health complications such as cardiovascular complications and depression (Brodaty and Donkin 2009). If the CH intervention achieves its goal of supporting caregivers by facilitating communication with health professionals and providing informational and social support, there may be positive effects on caregiver health and well-being manifested through stress buffering (Cohen 2004), thereby augmenting the benefits of the intervention.

In addition, if implementation of CH can reduce the cost of formal care by 5% as considered in the scenarios examined in this study, the CH intervention could free up a considerable amount of resources in the health care system. If 25% of the approximately 26,000 people in Ireland living with dementia in the community received the CH intervention (Connolly et al. 2014), a 5% reduction in the costs of formal care would total €630,500 per month or over €7.5 million per year using our cost of care estimates and assuming equal distribution of participating patients in mild and moderate disease states. While these savings may be offset by the cost of the intervention from an accounting perspective, from an economic perspective the reallocation of practitioners and other scarce resources to other uses would likely benefit the health system.

The cost and modeling approaches used in this study have some important advantages over alternative approaches. The TDABC approach to estimating costs ensured that all activities

contributing to the cost of care were included and allowed us to gather cost estimates on a constant set of activities from multiple sources. The resulting estimates are within the range of findings from other dementia cost of illness studies (Connolly et al. 2014; Quentin et al. 2010). Our findings concur with previous findings that the costs of informal care are a significant portion of total costs, and they increase as the disease progresses (Gillespie et al. 2015). The Markov framework explicitly models the changes in the costs of care and the quality of life over time. Because dementia is a long-lasting, degenerative condition with relatively stable transitions between states, such an approach is quite appropriate.

The cost-effectiveness estimates should be considered conservative because the intervention costs in the current study are likely greater than under a full-scale implementation. The per-patient costs of the intervention in the current study were based on a feasibility study with 28 patients for a duration of 6 weeks. A larger scale and longer study may find that the technical staff required to support the intervention may be able to handle a larger caseload, thus reducing the per-patient cost of the intervention and further improving cost-effectiveness. Moreover, research suggests that the third stage of dementia, the moderate-severe state, is often marked by an acute health event related to the progression of dementia for which the patient often receives care at a LTC facility. It is possible that routine monitoring through CH will reduce the probability of this acute event. Further research on the intervention should prioritize tracking these acute events among CH patients. With additional data, this model could be expanded to incorporate an additional health state or states to represent these costly events, accounting for the impact of the acute event on the cost-effectiveness of the intervention.

This study faces at least three important limitations. First, because of data limitations, the findings are based on a set of conjectured scenarios. The feasibility study on which some parameters were based was limited to 6 weeks, and yet dementia and its care proceeds over several years. In the place of direct estimates, we developed hypothetical scenarios that plausibly represented a large-scale deployment of CH technology. Further research should directly estimate the impact of CH on patients' cost of care, rate of progression through the disease states, and quality of life. Second, following the approach of a study in Sweden (Ekman et al. 2007), health utility values corresponding to each of the disease states in the current study were based on quality of life deteriorating linearly from the mild stage to death. Future research should measure the quality of life of Irish dementia patients in each state. Third, the source of costs for the current study was two large teaching hospitals in Dublin. Some overhead costs may vary considerably in other hospitals in Ireland. However, the salary costs are unaffected by this limitation.

Despite these limitations, the costing and modeling approaches described in this study provide a valuable framework for applied researchers interested in assessing the potential impact of new innovations in health care delivery. The current study offers an optimistic initial appraisal of the potential for CH and other interventions for people with dementia, but further research is needed. First, a larger study of the CH intervention is needed over a longer period to generate empirical estimates of the impact of the intervention on disease progression, cost of care, and patient quality of life. A useful intermediate step would be a value of information analysis using the model described in this study to guide the design of a larger pilot study of the intervention (Claxton and Sculpher 2006). Second, future studies of the CH intervention should be designed

in such a way to identify differences in rates of disease progression in subgroups defined by age and gender, and should also consider the cost-effectiveness of the intervention from alternative perspectives, such as a health system perspective versus a broader societal perspective. The latter perspective must consider the impact of the intervention on health outcomes of caregivers (Goodrich et al. 2012), who may experience higher quality of life given the additional resources and improved access to medical providers under CH.

Acknowledgements

The authors would like to acknowledge James Fullam, Ph.D., Denis Curtin, MD, and Sarah Cosgrove, RGN for their contributions to this research. Dr. Fullam contributed to the cost data collection, while Dr. Curtin and Ms. Cosgrove were involved in the feasibility study of the intervention. In addition, the authors thank two anonymous reviewers for their helpful feedback and suggestions.

Funding

This study was supported by Applied Research for Connected Health. The center is funded by industry, but the current study was performed independently, meaning at no point did industry direct the research activities and that the manuscript was not subject to review by industry partners prior to publication.

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Appendix: Sensitivity analysis

We conducted a sensitivity analysis to assess the extent to which different rates of disease progression impact our results. We derived monthly transition probabilities from Spackman et al. (2012). The transition probabilities for standard of care, as well as for two hypothetical scenarios characterized by 1 and 2 month delays in transitions from mild and moderate states are shown below in Table 6.

Table 6. Transition probabilities

From	To	Standard of care	Scenario 1 (1 month delay)	Scenario 2 (2 month delay)
Mild	Mild	0.975	0.976	0.977
Mild	Moderate	0.022	0.021	0.020
Mild	Dead	0.003	0.003	0.003
Moderate	Moderate	0.933	0.939	0.944
Moderate	Moderate-severe	0.044	0.039	0.034
Moderate	Dead	0.022	0.022	0.022
Moderate-severe	Moderate-severe	0.944	0.944	0.944
Moderate-severe	Severe	0.044	0.044	0.044
Moderate-SEVERE	Dead	0.012	0.012	0.012
Severe	Severe	0.947	0.947	0.947
Severe	Dead	0.053	0.053	0.053
Dead	Dead	1.000	1.000	1.000

Costs and health utility values are identical to those used to represent standard of care and scenarios 1 and 4 in the body of the paper. Those values are shown in Table 7.

Table 7. Cost and health utility values for sensitivity analysis scenarios

	Total monthly cost[a]	Utility value
Standard of care		
Mild	€3713	0.90
Moderate	€6083	0.68
Scenario 1		
Mild	€4197	Same as standard of care
Moderate	€6567	Same as standard of care
Scenario 4		
Mild	€4068	0.93
Moderate	€6307	0.70

[a] Includes both cost of care and cost of the intervention, when applicable

As noted in the main body of the paper, we calculated costs, QALYs and incremental costs per QALY over a 10 year timeframe due to the slower rate of disease progression observed by Spackman et al. (2012). To ease comparisons to our main results, we also present outcomes over 4 years in Table 8.

Table 8. Results from sensitivity analysis

	Per-patient costs	Cost relative to standard of care	Per-patient QALYs	QALYs relative to standard of care	Incremental cost per QALY
Over 4 years					
Standard of care	€164,006	N/A	2.39	N/A	N/A
Scenario 1	€178,920	€14,915	2.42	0.03	€519,633
Scenario 4	€173,383	€9377	2.51	0.12	€76,820
Over 10 years					
Standard of care	€266,385	N/A	3.35	N/A	N/A
Scenario 1	€289,078	€22,694	3.44	0.08	€273,272
Scenario 4	€283,412	€17,027	3.61	0.25	€66,941

QALY quality-adjusted life year