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Economic Evaluations of Multicomponent Disease Management Programs with Markov Models: A Systematic Review

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ABSTRACT

Background: Disease management programs (DMPs) for chronic diseases are being increasingly implemented worldwide. **Objectives:** To present a systematic overview of the economic effects of DMPs with Markov models. The quality of the models is assessed, the method by which the DMP intervention is incorporated into the model is examined, and the differences in the structure and data used in the models are considered. **Methods:** A literature search was conducted; the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement was followed to ensure systematic selection of the articles. Study characteristics e.g. results, the intensity of the DMP and usual care, model design, time horizon, discount rates, utility measures, and cost-of-illness were extracted from the reviewed studies. Model quality was assessed by two researchers with two different appraisals: one proposed by Philips et al. (Good practice guidelines for decision-analytic modelling in health technology assessment: a review and consolidation of quality assessment. *Pharmacoeconomics* 2006;24:355-71) and the other proposed by Caro et al. (Questionnaire to assess relevance and credibility of modeling studies for informing health care decision making: an ISPOR-AMCP-NPC Good Practice Task Force report. *Value Health* 2014;17:174-82). **Results:** A total of 16 studies (9 on chronic heart disease, 2 on asthma, and

5 on diabetes) met the inclusion criteria. Five studies reported cost savings and 11 studies reported additional costs. In the quality, the overall score of the models ranged from 39% to 65%, it ranged from 34% to 52%. Eleven models integrated effectiveness derived from a clinical trial or a meta-analysis of complete DMPs and only five models combined intervention effects from different sources into a DMP. The main limitations of the models are bad reporting practice and the variation in the selection of input parameters. **Conclusions:** Eleven of the 14 studies reported cost-effectiveness results of less than \$30,000 per quality-adjusted life-year and the remaining two studies less than \$30,000 per life-year gained. Nevertheless, if the reporting and selection of data problems are addressed, then Markov models should provide more reliable information for decision makers, because understanding under what circumstances a DMP is cost-effective is an important determinant of efficient resource allocation.

Keywords: chronic disease, cost-effectiveness, DMP, Markov model, review.

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Introduction

In the United States, 86% of all health care spending in 2010 was for people with at least one chronic disease [1]. Disease management programs (DMPs) for chronic diseases are being increasingly implemented in health care systems all over the world [2–4]. The primary long-term goal of DMPs is to decrease the cost of illness, in addition to improving disease control and health-related quality of life. DMPs consist of a system of coordinated health care interventions and communications for populations with conditions for which patient self-care is important [5,6]. To evaluate the cost-effectiveness of DMPs, clinical trials that

include cost data can be used. Nevertheless, they deal with only the time frame of the trial, whereas health economic models can extrapolate results into the future [7]. In particular, Markov models are useful when a decision problem involves an ongoing risk, when important events may occur more than once, and when the utility of an outcome depends on when it occurs [8]. Therefore, a Markov model may be a reliable tool for decision makers [9] because understanding under what circumstances a DMP is or is not cost-effective is an important determinant of efficient resource allocation [10].

We present a systematic overview of the economic results of DMPs in chronic diseases provided by Markov models. The

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quality of the models is assessed, and how the DMP intervention was incorporated into the model and how it fitted are examined. Finally, differences in the structure and data of the models on outcomes are estimated.

Methods

Data Sources and Searches

We followed the instructions of the standards of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (see Appendix I in Supplemental Materials found at <http://dx.doi.org/10.1016/j.jval.2016.07.004>) [11]. A systematic literature search was conducted on June 26, 2015 (see Appendix II in Supplemental Materials found at <http://dx.doi.org/10.1016/j.jval.2016.07.004>). The databases PubMed, Embase, Business Source Complete, and EconLit were screened for articles using the following search terms: *disease management/disease management programme/management program; decision analytic/model/Markov; chronic disease/COPD/asthma/breast cancer/diabetes/coronary/heart*. After removing duplications, abstracts were screened. For inclusion, the following a priori defined criteria had to be fulfilled: 1) effects and costs were considered, 2) publication year was after 1995, 3) a Markov model was used, 4) articles were in either English or German, and 5) physicians and patients played an active role in the DMP process. Subsequently, all articles that were considered potentially eligible by at least one reviewer were subject to full-text analysis. The reference lists of these studies were searched to find additional relevant literature. Any disagreements on inclusion of studies were solved by consensus.

Data Extraction

Data extraction was performed by one investigator. The fulfillment of the requirements of the Disease Management Association of America on full-service DMPs was considered. As far as we know, there is no standard or validated method to grade the intensity of a DMP or of usual care. Therefore, we took a pragmatic approach. An intervention that met all six requirements was assessed as a high-intensity treatment, one that met five was medium intensity, and one that met fewer than five was low intensity. The degree of care in the control group was divided into low-, medium-, and high-intensity care. High intensity was achieved if a management plan and patient education were provided, medium intensity if one of these was provided, and low intensity if neither was provided.

Differences in costing year were addressed by using the gross domestic product index of the Organisation for Economic Co-operation and Development [12]. First, the costs were inflated to the price year 2011 in the original country and then converted into US \$ to US purchasing power parities.

Quality Assessment

Model quality was assessed with two appraisals: one proposed by Philips et al. [13] in 2006 and the other proposed by Caro et al. [14] in 2014. One amendment was made to the framework of the appraisal of Philips et al. [13]: quality items concerning costs from the 2004 appraisal [15] were added. Because this review is not written from the perspective of a specific decision maker, the first part of the Caro et al. [14] appraisal, which addressed the extent to which the results of the model apply to the setting of interest to the decision maker, was not considered further. All items in the quality appraisals evaluated as not available were rated as not fulfilled for the descriptive analysis of the quality appraisals. The quality assessment was performed by two researchers, and

any disagreements on the rating of items were solved by consensus.

Results

Literature Search

The literature search (Fig. 1) yielded a total of 3180 citations. After removing 799 duplications, 2381 abstracts were screened and the full-text articles of 66 citations plus 39 citations from reference lists were reviewed. A total of 16 studies met the inclusion criteria: 9 studies focused on chronic heart disease, 2 on asthma, and 5 on diabetes.

Additional study characteristics can be found in Tables 1 to 3, and the costs and utility values incorporated into the model are provided in Tables I and II in Supplemental Materials found at <http://dx.doi.org/10.1016/j.jval.2016.07.004>.

Economic Results

For DMPs in chronic heart disease, the results ranged from cost savings of \$657 and an increase of 0.0051 quality-adjusted life-years (QALYs) [16,17] to additional costs of \$4,607 per life-year gained (LYG) [18] and \$146,544 per QALY [19]. Three studies [16–18] reported cost savings and six studies [19–24] reported additional costs.

The two studies for asthma reported cost savings of \$798 and a gain of 0.62 QALYs [22], or additional costs of \$3635 per QALY [25].

The remaining five studies for diabetes reported results from cost savings, which were not specified further in one study [26], to additional costs, of up to \$21,701 per LYG [27] and \$85,087 per QALY [24].

Quality Assessment

In the Philips et al. [13] quality appraisal, the overall score results for chronic heart disease ranged from 39% [18] to 65% [23], for asthma from 53% [25] to 58% [22], and for diabetes from 45% [27] to 53% [28] (see Table III in Supplemental Materials found at <http://dx.doi.org/10.1016/j.jval.2016.07.004>, and also Fig. 2).

For the Caro et al. [14] quality appraisal, the overall scores for chronic heart disease ranged from 34% [18] to 52% [20,21,23,29], for asthma from 31% [25] to 38% [22], and for diabetes from 34% [28] to 51% [30] (see Table IV in Supplemental Materials found at <http://dx.doi.org/10.1016/j.jval.2016.07.004>, and also Fig. 3).

The performance of the models for the subdimensions and each item for the Philips et al. [13] and Caro et al. [14] quality appraisals can be found in Tables III and IV in Supplemental Materials and in Figures 2 and 3. Chronic heart disease models performed the best, with average overall scores of 55% and 48% in the Philips et al. [13] and Caro et al. [14] quality appraisals, respectively, compared with 56% and 36% for asthma and 50% and 43% for diabetes. In the Philips et al. [13] quality appraisal, the chronic heart disease models performed the best in the dimension structure, with an average overall score of 65% versus 61% for asthma and 62% for diabetes.

There was only a slightly positive trend in the quality of results over time, and the average overall score from models published from 2010 onward [16,17,19,26,31,32] was 57% versus 51% from models published before 2010 [18,20–25,27,28,30] in the Philips et al. [13] quality appraisal and was 47% versus 43% in the Caro et al. [14] quality appraisal. To see whether the models were ranked in the same order in both quality appraisals, the Spearman rank correlation coefficient was calculated as 0.262 with a *t* value of 1.016. This low value shows that the correlation between the two quality appraisals is weak, although the positive value

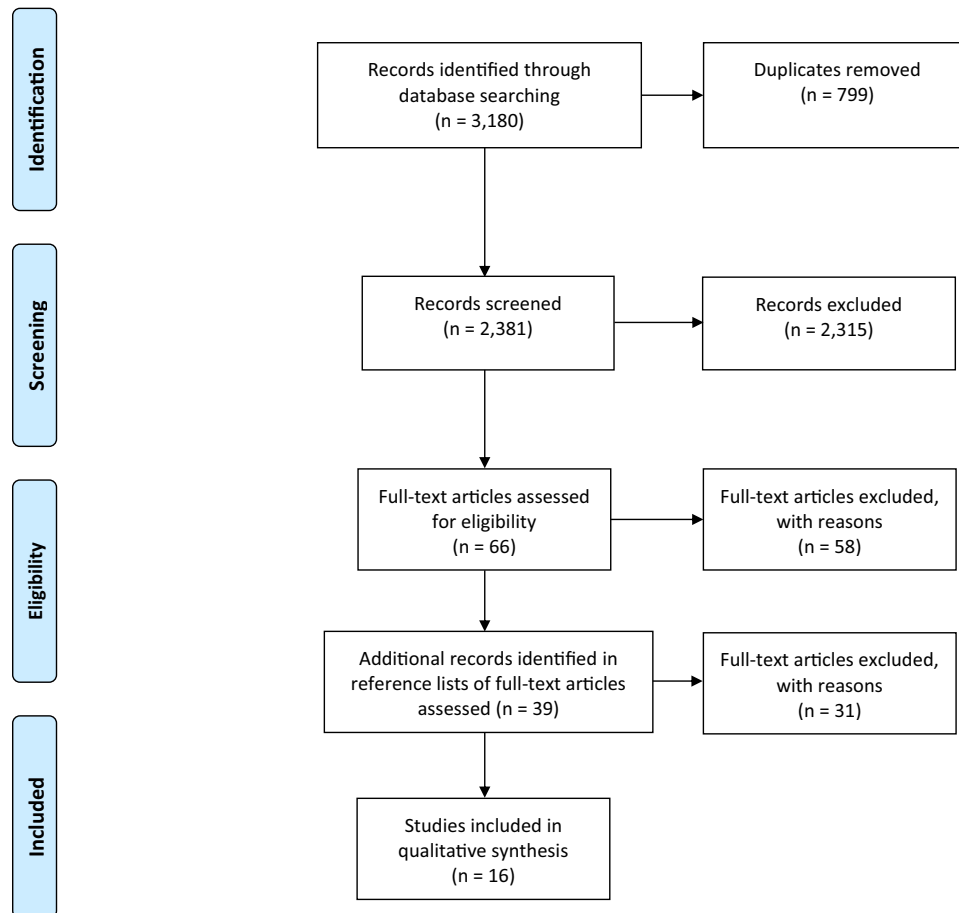


Fig. 1 – Prisma 2009 flow diagram.

suggests that a high score in one tends to lead to a high score in the other quality appraisal.

Incorporation of DMPs into the Models

Nearly all models [16–18,20–23,25,26,29,30] integrated effectiveness derived from a clinical trial or a meta-analysis of complete DMPs. Only five models [19,24,27,28,32], two for chronic heart disease [19,32] and three for diabetes [24,27,28], used different sources and combined the different interventions into a DMP.

Gandjour [32] constructed a model for hypertension, and the DMP reduced the nonadherence rate in patients and in physicians, leading to a relative risk reduction in stroke, myocardial infarction (MI), and death [33]. For MI, Ito et al. [19] evaluated improvements in medication adherence from informational, behavioral, and complex interventions and from combinations of these interventions. The effectiveness rates for each single intervention were derived from systematic reviews and meta-analyses [34–36], and for the combined interventions the effectiveness rates were based on the authors' assumptions that were not described further in the reference.

The remaining three models were for diabetes. Huang et al. [28] used different sources for the effects of angiotensin-converting-enzyme (ACE) inhibitors [37,38] and aspirin [39], and stated that they assumed that the joint effect of aspirin and ACE inhibitors on cardiovascular effects was multiplicative. Gilmer et al. [24] reported that a clinical database stored the medical and epidemiological data, which were not described further in the study. The data were directly implemented in the model to

calculate clinical outcomes. The interaction of the effects, however, remained unclear. Palmer et al. [27] incorporated probability reductions for ACE inhibitors and intensive therapy from different sources and added several further interventions to usual care and to intensive therapy, and thus it is not clear whether the additional effects were additive or multiplicative.

Structure

The bubble charts of the Markov models can be found in Appendix III in Supplemental Materials found at <http://dx.doi.org/10.1016/j.jval.2016.07.004>.

Chronic heart disease

Chronic heart disease encompasses many different diseases, including chronic heart failure, hypertension, congestive heart failure (CHF), MI, and coronary heart disease (CHD).

The chronic heart failure models ranged from five states [21] to over six [18] and eight states [29]. Starting at index hospitalization [21,29] or no previous hospitalization [18], further hospitalizations were possible before death occurred.

The two hypertension models in that review were published by Gandjour [23,32] and both had five states (no cardiovascular disease, renal failure, MI, stroke, and death).

Only the model reported by Miller et al. [20] dealt with CHF and had four states (New York Heart Association [NYHA] classification I, II, III and IV, and death).

Table 1 – Study characteristics I.

Author	Country	Disease	Population identification process	Evidence-based practice guidelines	Collaborative practice models	Patient self-management education	Process and outcomes measurement, evaluation, and management	Routine reporting/feedback loop	Intervention group	Control group
Moertl et al. [29]	Austria and Canada	Chronic HF	✓	✓	✓	✓	✓	✓	6/6 high intense	Medium intense (management plan)
Chan et al. [18]	United States	HF	✓	✗	✓	✓	✓	✓	5/6 medium intense	Medium intense (patient education)
Göhler et al. [21]	Germany	Chronic HF	✓	✗	✓	✓	✓	✓	5/6 medium intense	Low intense
Gandjour [32]	Germany	Hypertension	✓	✓	✗	✓	✓	✓	5/6 medium intense	Low intense
Gandjour and Stock [23]	Germany	Hypertension	✓	✓	✗	✓	✓	✓	5/6 medium intense	Low intense
Miller et al. [20]	United States	CHF	✓	✓	✓	✓	✓	✓	6/6 high intense	Low intense
Gillespie et al. [17]	Ireland	CHD	✓	✓	✓	✓	✓	✓	6/6 high intense	Northern Ireland: medium intense (management plan); Republic of Ireland: low intense
Gillespie et al. [16]	Ireland	CHD	✓	✓	✓	✓	✓	✓	6/6 high intense	Northern Ireland: medium intense (management plan); Republic of Ireland: low intense
Ito et al. [19]	United States	MI	✓	✓	✓	✓	✓	✓	6/6 high intense	Low intense
Steuten et al. [22]	The Netherlands	Asthma	✓	✓	✓	✓	✓	✓	6/6 high intense	Medium intense (patient education)
Gordois et al. [25]	Australia	Asthma	✓	✓	✓	✓	✓	✓	6/6 high intense	Low intense
Yu et al. [26]	United States	Type 2 diabetes	✓	✓	✓	✓	✓	✓	6/6 high intense	Low intense
Huang et al. [28]	United States	Type 2 diabetes	✓	✓	✓	✓	✓	✓	6/6 high intense	Medium intense (management plan)

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CHD, coronary heart disease; CHF, congestive heart failure; HF, heart failure, MI, myocardial infarction.

The time horizons used by the models for chronic heart disease were 15 years [18], 20 years [29], 35 years [23], 50 years [16], and 55

Table 2 – Study characteristics II.

Author	Effectiveness of intervention	Cost of intervention (2011 US \$ prices)	Perspective	Model design	Study population	Study design intervention data derived
Moertl et al. [29]	Different transition probabilities for Rehospitalization: UC: 1.2; nurse-led MC: 0.8; BMC: 0.4 Clinic visits scheduled: UC: 0; nurse-led MC: 2.3; BMC: 3.7 Clinic visits unscheduled: UC: 2.5; nurse-led MC: 3.0; BMC: 2.5 Higher quality-adjusted survival rate: UC: 0.9; nurse-led MC: 0.99; BMC: 1.01 Beta blocker therapy: RR of death = 0.56; RR of rehospitalization: 0.66	Austria/Canada: UC: \$124/\$217 Nurse-led MC: \$676/ \$630 BMC: \$827/\$805	Third-party payer	Eight-state Markov model: No additional hospitalization, first additional hospitalization, status after 1 additional hospitalization, second additional hospitalization, status after 2 additional hospitalizations, third or more additional hospitalization, status after at least 3 additional hospitalizations, and death	278 adults discharged from HF hospitalization	Clinical trial
Chan et al. [18]	Different transition probabilities for UC/ disease management for Death hospitalized: 0.203/0.192 Death not hospitalized: 0.007/0.007 No previous hospitalization: 0.008/0.006 1 previous hospitalization: 0.052/0.038 2 previous hospitalizations: 0.106/0.038 3 previous hospitalizations: 0.121/0.088 4+ previous hospitalizations: 0.180/0.131	\$864 in the first year, then the intervention stops	Not in text	Six-state-Markov model: No previous hospitalization, 1 previous hospitalizations, 2 previous hospitalizations, 3 previous hospitalizations, 4+ previous hospitalizations, and death	1000 patients with HF: ejection fractions of ≤35% on ACE inhibitors and other conventional drugs	Clinical trial
Göhler et al. [21]	Transition probabilities Control group: Index hospitalization: hospitalized death 0.067; nonhospitalized death 0.010; rehospitalization 0.168; Rehospitalization 1: hospitalized death 0.075; nonhospitalized death 0.012; rehospitalization 0.213; Rehospitalization 2: hospitalized death 0.085; nonhospitalized death 0.013; rehospitalization 0.268; Rehospitalization 3+: hospitalized death 0.095; nonhospitalized death 0.015; rehospitalization 0.334 Intervention group: Relative risk for all-cause mortality: 0.81 Relative risk for all-cause rehospitalization: 0.84	\$573 initiation costs	Societal perspective	Five-state Markov model: Index hospitalization, rehospitalization 1 to 3+, and death	Adults with CHF (mean age 67 y) on the basis of German data in the EuroHeart Failure Survey	Meta-analysis
Gandjour [32]	Noncompliance reduction: patients 20% and physicians 9% [19,50] Relative risk of adherent patients for: Stroke: 0.71 MI: 0.79 Death: 0.90	\$1231 per patient per year	Third-party payer	Five-state Markov model: No cardiovascular disease, MI, stroke (including transient ischemia), renal failure, and death	Adults from 40 to 69 y with hypertension and without cardiovascular disease at model start	Clinical trial
Gandjour and Stock [23]	Relative risk of patients in the disease management group for: Stroke: 0.71 MI: 0.79 Death: 0.90	\$229 per patient per year	Third-party payer	Five-state Markov model: No cardiovascular disease, MI, stroke (including transient ischemia), renal failure, and death	Hypothetical cohort of hypertensive male and female patients without cardiovascular disease at different	Mainly meta-analyses

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Miller et al. [20]	Different transition probabilities for control group/disease management group from Month 0-6: NYHA I: to I 57.9%/67.4%; to II 36.8%/29.2%; to III & IV 5.35%/3.4% NYHA II: to I 18.3%/21.6%; to II 66.4%/64.8%; to III & IV 15.4%/13.6% NYHA III & IV: to I 5.1%/7.4%; to II 48.7%/35.8%; to III & IV 46.2%/56.8% Subsequent periods: NYHA I: to I 61.7%/61.1%; to II 31.9%/33.2%; to III & IV 6.4%/5.8% NYHA II: to I 16.9%/22.3%; to II 60.5%/59.5%; to III & IV 22.7%/18.2% NYHA III & IV: to I 3.0%/4.5%; to II 35.8%/29.3%; to III & IV 61.2%/66.2%	\$3610 per patient per year	Third-party payer	Four-state Markov model: NYHA I, NYHA II, NYHA III and IV, and death	age groups (40–49, 50–59, and 60–69 y) 1069 adult patients with echocardiographic evidence of CHF (751 of them suffered from systolic heart failure)	Clinical trial
Gillespie et al. [17]	Different transition probabilities for control group/intervention group for coronary events (stable angina, unstable angina, MI and CHD death), post-MI, and death. No numbers stated in the text or the technical appendix	\$273 per patient per year	Third-party payer	Three-state Markov model: CHD, post-MI, and death	838 adults with CHD excluding patients with angina only and diabetes	Clinical trial
Gillespie et al. [16]	Different transition probabilities for control group/intervention group for coronary events (stable angina, unstable angina, MI and CHD death), post-MI, and death. No numbers stated in the text or the technical appendix	\$273 per patient per year	Third-party payer	Three-state Markov model: CHD, post-MI, and death	903 adult patients with CHD (documented MI, CABG, angioplasty, or angina)	Clinical trial
Ito et al. [19]	Relative risk of post-MI patients by number of drugs MI: 1 drug: 0.77 2 drugs: 0.60 3 drugs: 0.44 4 drugs: 0.35	Disease management \$368; mailed education \$10; polypills \$2477; pharmacotherapy \$359 (2012) to \$211 (2018) Stroke: 1 drug: 0.87 2 drugs: 0.69 3 drugs: 0.61 4 drugs: 0.47	Societal perspective CHF: 1 drug: 0.90 2 drugs: 0.82 3 drugs: 0.73 4 drugs: 0.65	Five state Markov model: post-MI, post-MI and recurrent MI, post-MI and CHF, post-MI and stroke, and death	Hypothetical cohort of patients 65 y of age who were discharged alive after MI and were prescribed all four classes of guideline-recommended post-MI therapy	Clinical trial
Steuten et al. [22]	Different transition probabilities UC/disease management from: Successful control: to successful control 0.956/0.972; to suboptimal control 0.024/0.016; to primary care exacerbation 0.17/0.10; and hospital exacerbation 0.003/0.002 Suboptimal control: to successful control 0.100/0.300; to suboptimal control 0.885/0.691; to primary care exacerbation 0.014/0.008; and hospital exacerbation 0.001/0.001 Primary care exacerbation: to successful control 0.031/0.146; to suboptimal control 0.225/0.156; to primary care exacerbation 0.576/0.568; and hospital exacerbation 0.168/0.130	\$136 overhead per year per patient	Societal perspective	Five-state Markov model: Successful control, suboptimal control, primary care-managed exacerbation, hospital-managed exacerbation, and all causes of death	658 adults with asthma	Clinical trial

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Table 2 – continued

Author	Effectiveness of intervention	Cost of intervention (2011 US \$ prices)	Perspective	Model design	Study population	Study design intervention data derived
Gordois et al. [25]	Hospital exacerbation: to successful control 0.008/0.222; to suboptimal control 0.442/0.341; to primary care exacerbation 0.149/0.228; and hospital exacerbation 0.329/0.209 Different transition probabilities UC/disease management from: Severe asthma: to severe 0.798/0.552; to moderate 0.186/0.366; to mild 0.016/0.083 Moderate asthma: to severe 0.0373/0.333; to moderate 0.529/0.400; to mild 0.098/0.267 Mild asthma: to severe 0.333/0.400; to moderate 0.000/0.677; to mild 0.000/0.600	\$991 (per patient in 5 y)	Third-party payer	Four-state Markov model: Mild, moderate, severe asthma and death	351 patients with asthma	Clinical trial
Yu et al. [26]	Different transition probabilities for enhanced care group and control group for nonfatal/fatal CHD and nonfatal/fatal stroke: Control group Nonfatal CHD from year 1: 1.20% to year 10: 14.80% Fatal CHD from year 1: 0.70% to year 10: 10.30% Nonfatal stroke from year 1: 0.50% to year 10: 8.30% Fatal stroke from year 1: 0.10% to year 10: 1.10% Enhanced care group Nonfatal CHD from year 1: 0.70% to year 10: 9.30% Fatal CHD from year 1: 0.40% to year 10: 5.7% Nonfatal stroke from year 1: 0.40% to year 10: 6.80% Fatal stroke from year 1: 0.00% to year 10: 0.90%	Not found in text	Third-party payer	Eleven-state Markov model: Not described further	611 adult patients with diabetes type 2 (204 in intervention group and 407 in control group)	Retrospective matched-cohort study
Huang et al. [28]	Different transition probabilities for control group and disease management group Glucose control beneficial effect on microvascular events but not on cardiovascular events (estimated with the UKPDS risk prediction) ACE inhibitors benefits not further described Aspirin reduces the probability of CHD and increases the probability of gastrointestinal bleed Comparison of probabilities or differences not stated in the text or the technical appendix	Year 1: \$848 Year 2: \$715 Year 3: \$562 Year 4: \$450 per patient per year	Societal perspective	Markov model (number of states not in text)	Nonpregnant adult patients (18–75 y) with diabetes	Serial cross-sectional study
Gilmer et al. [24]	Not mentioned in text. In the technical appendix, the following can be found: “clinical database: it is a set of	Year 1: \$2554 Year 2 and beyond: \$2222	Third-party payer	Fifteen state Markov model: Angina, MI, CHF, stroke, peripheral vascular disease,	3893 patients with diabetes	Pre-post observational study

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	probabilities and risk adjustment factors for disease progression and the occurrence of acute event or complication, which are based on physiological parameters and/or patient states and characteristics."			diabetic retinopathy, macula edema, cataract, hypoglycemia, ketoacidosis, lactic acidosis, nephropathy, neuropathy, foot ulcer and amputation, and nonspecific mortality		
Mason et al. [30]	Transition probabilities not mentioned in text. Only the following can be found: "The model applies Framingham risk equations each year to patients in the healthy state to calculate the risk of suffering a stroke or MI according to their age, sex, and cardiovascular risk factors."	Blood pressure control: \$748 per patient per year Lipid control: \$1098 per patient per year	(Not in text) only direct costs were considered	Four-state Markov model: "Healthy" diabetes, nonfatal MI, stroke, and death	1407 subjects attending the diabetes center at Hope Hospital, Salford, UK, with raised blood pressure and hyperlipidemia	Clinical trial
Palmer et al. [27]	Reduction of relative risk for complications of diabetes for the single interventions ACE: 55% reduction in the rate of annual increase in urinary albumin excretion ACE: 50% reduction in probability (macroalbuminuria to end-stage renal disease) Intensive therapy: 76% reduction in incidence background retinopathy Intensive therapy: 47% reduction in progression background retinopathy to proliferative retinopathy Intensive therapy: 0% or 41% reduction in diabetes-attributed probability AMI/probability stroke/probability amputation	Not in text (but cited)	Third-party payer	Markov model with 7 submodels: Renal disease, retinopathy, amputation, MI, stroke, major hypoglycemic events, and ketoacidosis	Newly diagnosed 19-y-old	Clinical trial

ACE, angiotensin-converting-enzyme; AMI, acute myocardial infarction; BMC, intensive patient management; CABG, coronary artery bypass grafting; CHD, coronary heart disease; CHF, congestive heart failure; HF, heart failure; MC, multidisciplinary care; MI, myocardial infarction; NYHA, New York Heart Association; RR, relative risk; UC, usual care; UKPDS, U.K. Prospective Diabetes Study.

years [32] to lifetime [17,20,21]; for asthma, both models [22,25] used a time horizon of 5 years; and for diabetes, the time horizon range was from 10 years [26] and over 40 years [24] to lifetime [27,28,30].

Discount rates

For chronic heart disease, the discount rates ranged from 3% [19,20,23,32] to more than 3.5% [16,17] and to 5% [21,29]; for asthma, between 4% [22] and 5% [25]; for diabetes, between 3% [24,26–28] and 5% [26,30] for costs and effects in the base case. Only Yu et al. [26] used different discount rates for costs (5%) and effects (3%) in diabetes.

Utility weights

Fourteen [16,17,19–26,28,30–32] out of 16 models estimated QALYs as the outcome measure, and thus incorporated utility values (see Table 1 in Supplemental Materials).

Utility values across indication area. The models were conducted in three indication areas; therefore, many possible disease states were considered. Nonetheless, there were overlaps in chronic heart disease and diabetes, which both included stroke, CAD, MI, and renal failure. For asthma, no overlaps with diabetes or chronic heart disease were identified. The incorporated values for stroke (six models [19,23,26,28,30,32]) ranged from 0.5 [30] to 0.675 [26]; for CAD (three models) from 0.6877 [16,17] to 0.77 [26]; for MI (six models) from 0.6542 [17] to 0.88 [23,28,30,32]; and for renal failure (three models [23,28,32]), 0.61. The highest absolute spread could be found in MI, but only Gillespie et al. [17] used a utility value of 0.6542, whereas all other models incorporated a value higher than 0.77. The highest percentage spread of 35% was found in stroke.

Utility values within indication area. In chronic heart disease, Moertl et al. [29] and Göhler et al. [21] used the highest utility values in the models for chronic heart failure, followed by the value used by Ito et al. [19] in their MI model. Gandjour and Stock [23] and Gandjour [32] used the same utility values in their hypertension models, which were lower than the utility values in the chronic heart failure and MI models. Miller et al. [20] and Gillespie et al. [16,17] used the lowest utility values in their CHF and CHD models.

For asthma, Gordoïs et al. [25] used higher utility values than did Steuten et al. [22] on average, even when the disease states were not totally comparable.

For well-being in diabetes, Yu et al. [26] incorporated the lowest value and Huang et al. [28] and Mason et al. [30] the highest. Moreover, the incorporated values for comparable complications were similar.

The differences in incorporated utility values were greater in the models for chronic heart disease and asthma than for diabetes.

Cost of illness

Although not every model considered all kinds of costs, as far as was possible, a quantitative comparison was conducted (see Table 2 in Supplemental Materials).

In chronic heart disease, Moertl et al. [29] used hospitalization costs (\$12,819/\$19,807) more than twice those used by Chan et al. [18] (\$5,759) and Göhler et al. [21] (\$5,960). Gandjour and Stock [23] and Gandjour [32] used a rate for a physician visit (\$66) that was twice that used by Moertl et al. [29] (\$23/\$35). Göhler et al. [21] used medication costs (\$655) that were 2 to 3 times higher than those used in all other models [19,23,29,32].

For asthma, Steuten et al. [22] incorporated the highest costs in every category.

For diabetes, Gilmer et al. [24] used the highest medication costs (\$1,872) compared with \$639 [27] and \$1,477 in other models [26]. Yu et al. [26] used the highest costs for CHD (\$37,462) and stroke (\$32,916) compared with those used by Palmer et al. [27] (stroke: \$26,197) and Huang et al. [28] (stroke: year 1 survivor \$26,362; year 1 nonsurvivor \$41,633; CHD: \$12,104).

Sensitivity of parameters

Seven [16,17,19–21,23,29] of the nine chronic heart disease models, both [22,25] the asthma models, and four [24,26,28,30] of the five diabetes models (i.e., a total of 13 out of 16 models) conducted univariate sensitivity analyses.

Funding

Independent of the indication area, industry-funded studies or studies without a conflict of interest statement [18,20,22,23] were more likely to report a worse cost-effectiveness ratio than studies supported by an institutional grant [16,17,21] or without financial support [32]. For chronic heart disease, one study [29] was industry-funded, for asthma none was, and for diabetes three [24,27,30] out of five were.

Discussion

Economic Results

Fourteen studies [16,17,19–26,28–30,32] reported QALYs and two studies [18,27] reported LYG as outcome measures. The results ranged from cost savings of \$657 and a gain of 0.0051 QALYs [16,17] to additional costs of \$4,607 per LYG and \$146,544 per QALY [19] for chronic heart disease; from cost savings of \$798 and a gain of 0.69 QALYs [22] to additional costs of \$3,635 per QALY [25] for asthma; and from cost savings that were not described further [26,27] to additional costs of \$21,701 per LYG [27] and \$85,087 per QALY [24] for diabetes. It would, however, be premature to conclude that DMPs in asthma would have the best incremental cost-effectiveness, because there were only two models for asthma, five for diabetes, and nine for chronic heart disease. Therefore, the scatter of the results was greater. In addition, the incremental cost-effectiveness ratio is influenced by several factors, which are discussed after the section on quality assessment.

Quality of the Models

On the basis of the reported percentages presented in the Results section, the quality of the models was far from perfect. The major weaknesses were in the consistency of the dimensions in the Philips et al. [13] quality appraisal and in the reporting of dimensions and validation in the Caro et al. [14] quality appraisal. This low percentage for consistency in the Philips et al. [13] quality appraisal can be explained by the fact that three out of five items in the consistency subdimension refer to model validation, and they were not performed or at least not reported alongside the models. Nonetheless, this is consistent with the low score the models achieved in the list reported by Caro et al. [14], because reporting of model characteristics and input parameters was partially opaque and incomplete. The weak value of the Spearman correlation coefficient may have resulted from the slight difference in focus of the two quality appraisals.

Incorporation of DMPs into the Models

In contrast to pure pharmaceutical interventions, DMPs are a broad array of different interventions, and consequently there a huge number of possible combinations for DMPs, for which all the incremental cost-effectiveness ratios should be evaluated. Markov models can obtain these ratios by assuming that combining these interventions has additive and multiplicative effects. The main approach used is relative static, similar to the economic evaluation of pure pharmaceutical products [39], which ignores the capacity Markov models provide for evaluating multicomponent interventions. Nearly all models [16–18,20–23,25,26,29,30] use effectiveness rates derived from complete DMPs. The advantage of this approach is that both overestimation and underestimation caused by the accumulation of independently determined effects are avoided. Nevertheless, there are also disadvantages; because only the complete intervention is evaluated, it is not clear what contribution the individual treatments in the DMP make to the overall effect. Only five models [19,24,27,28,32] combined the effects of different interventions to obtain the right DMP for their purpose. Three [24,27,28] of these studies were conducted in diabetes. Remarkably, two [24,28] of the three studies did not report transition probabilities in a transparent way, meaning that how the individual effects of interventions combined in a DMP were incorporated into the model (e.g., multiplicative or additive) could not be reconstructed. If different sources are used to assemble a DMP, the modelers should mention and justify the assumptions made about how the effects of the interventions interact with each other. This type of approach, similar to the approaches of Palmer et al. [27] for diabetes and Ito et al. [19] for chronic heart disease, would be particularly valuable, despite the uncertainty that arises from combining the interventions, because this would allow a hierarchical ranking of partial interventions and enable prioritization of medical services. No comment can be made on the reliability of the effect values because the quality of the origins of the data was not assessed. Although there were restrictions in the level of detail, the descriptions were consistent with how the interventions were incorporated into the models, irrespective of the fact that the effects were taken from a complete DMP or were combined from single interventions into a DMP.

Structure

An increasing number of health care states considered by a model reflect a higher number of considered comorbidities that can be caused by a disease. Generally, a Markov model with more possible states considering more disease-related costs, which can be avoided by successful disease control, leads to a favorable incremental cost-effectiveness ratio [39].

For chronic heart disease, the model structures were similar; therefore, a potential overestimation or underestimation of the results because of the model structure can be neglected.

For asthma, however, exacerbations are the main driver of cost of illness, and thus the inclusion [22] or exclusion [25] of exacerbations should have a high impact on results. Gordoïs et al. [25] did not state the cost of illness or miscellaneous costs, and the costs for ambulatory care, medication, and inpatient care were higher in the model by Steuten et al. [22]. If the unlisted cost of illness and miscellaneous costs incorporated by Gordoïs et al. [25] are not substantially higher than the costs used by Steuten et al. [22], it is safe to expect an underestimation of the considered disease-related costs by Gordoïs et al. [25].

For diabetes, the number of states varies greatly because DMPs lead to better disease control and prevention of complications. Consequently, more disease states should lead to a better

incremental cost-effectiveness ratio for the intervention program, even when the basic orientation of all diabetes models (including cardiovascular diseases as comorbidities) is the same.

Data

DMP and usual care

Normally, high-intensity interventions are more effective but are also more expensive. If we ignore the poor reporting, which made classification difficult, low- [27] or high-intensity DMPs [16,17,19,20,22,24–26,28–30] are more cost-effective than medium-intensity DMPs [18,21,23,32]. This may be because DMPs are less effective or the usual care is much better for chronic heart disease, than for asthma or diabetes, because all medium-intensity DMPs were conducted for chronic heart disease.

The description of the usual care content was worse than that of the interventions. Usual care, however, is particularly important in a strongly context-dependent intervention, such as a DMP, the incremental effectiveness of which depends on background clinical practice patterns [10]. For DMPs, exactly the same rigor in describing the intervention and usual care should be applied as in pharmaceutical clinical trials, because even usual care for chronic diseases may be a multicomponent intervention.

Time horizon

The time horizon is particularly crucial for chronic conditions, because the economic benefits of DMPs of the reduction in resource utilization may not become evident in a short time frame. Some findings suggest that it takes at least 3 to 5 years, because of time lags in reaching full implementation, to obtain full program effectiveness [40]. Therefore, the short time horizons considered in asthma may have a negative impact on the cost-effectiveness ratio. Nevertheless, DMPs are ongoing interventions in which disease control takes priority. In contrast, in a once-only intervention, such as a pharmaceutical smoking cessation intervention, the positive impact of the intervention takes time to become evident, but no further costs arise. The positive impact of a longer time horizon on cost-effectiveness for a DMP should be smaller. Only the study by Gandjour and Stock [23] estimated the cost-effectiveness of a DMP in hypertension for time horizons of 35, 45, and 55 years. The results differed only marginally for low-risk patients with a starting age between 40 and 49 years at \$14,864 per QALY (maximum time horizon of 55 years), a starting age of 50 to 59 years at \$13,132 per QALY (maximum time horizon of 45 years), and a starting age of 60 to 69 years at \$14,239 per QALY (maximum time horizon of 35 years). The variance for high-risk patients was even smaller and was within a range of \$180 for the different age groups and time horizons. The time horizon is mostly lifetime and varies more between the indication areas than within an indication area, and its overall effect on the results should be small.

Discount rates

Even the small spread of 2% (or 3–5%) in discount rates between the models can have a large effect. High discount rates for future gains in health-related quality of life and costs negatively affect cost-effectiveness; for DMPs, future savings in cost of illness are expected. In contrast, the intervention costs are generally small compared with the potential savings of the intervention.

Utility weights

It is hard to find adequate utility measures to assemble models, and models that are more complex face higher risks in incorporating data, which may not fit. Some methodological problems

Table 3 – Study characteristics III.

Author	Cycle length	Discount rate costs (%)	Discount rate effects (%)	Time horizon	Price year	Results in US \$ (prices of 2011)
Moertl et al. [29]	1 mo	5	5	20 y	2010	Austria/Canada: UC: \$44,941/\$47,909 and 2.36 QALYs; MC: \$48,106/\$51,039 and 3.04 QALYs; BMC: \$43,752/\$46,430 and 3.20 QALYs
Chan et al. [18]	1 mo	3	3	15 y	2005	Baseline-risk patients improved life expectancy by 0.42 life-years for an additional cost of about \$4,607
Göhler et al. [21]	1 mo	5	5	Lifetime (until all patients who had not already died reached an age of 120 y)	2007	\$12,145 per QALY
Gandjour [32]	Not in text	3	3	55 y (maximum)	2004	\$19,379 per QALY
Gandjour and Stock [23]	1 y	3	3	35, 45, and 55 y	2004	Low-risk patients: High-risk patients: 40–49 y \$14,864 per QALY 40–49 y \$1,153 per QALY 50–59 y \$13,132 per QALY 50–59 y \$1,268 per QALY 60–69 y \$14,239 per QALY 60–69 y \$1,091 per QALY
Miller et al. [20]	6 mo	3	3	Lifetime (not described further)	2003	\$53,373 per QALY
Gillespie et al. [17]	1 y	3.5	3.5	Lifetime (not described further)	2006	Cost savings of \$657 and health gain of 0.0051 QALYs
Gillespie et al. [16]	1 y	3.5	3.5	50 y (maximum)	2006	Cost savings of \$657 and increase of 0.0051 QALYs
Ito et al. [19]	3 mo	3	3	Lifetime (not described further)	2010	Mailed education plus DMP: \$76,987; DMP: \$71,414; DMP plus polypill: \$137,256; polypill plus mailed education: \$116,616; polypill plus DMP: \$146,544
Steuten et al. [22]	2 wk	4	4	5 y	2004	Cost savings of \$798 and health gain of 0.69 QALYs
Gordois et al. [25]	6 mo	5	5	5 y	2006	With annual review: \$3,635 per QALY Without annual review: \$2,194 per QALY
Yu et al. [26]	1 y	3	5	10 y	2011	Cost savings of \$8,788 and 0.498 QALYs gained
Huang et al. [28]	1 y	3	3	Lifetime (not described further)	2004	\$39,786 per QALY
Gilmer et al. [24]	Not in text	3	3	Lifetime (40 y)	2003	Uninsured cohort: \$12,400 per QALY CMS cohort: \$30,060 per QALY Medi-Cal cohort: \$54,952 Commercial cohort: \$85,087
Mason et al. [30]	1 y	5	5	Lifetime (not described further)	2003	Blood pressure control: \$4,971 per QALY Lipid control: \$24,672 per QALY
Palmer et al. [27]	1 y	3	3	Lifetime (not described further)	1996	All conventional insulin strategies with an add-on are dominant (cost saving) Intensive insulin therapy with add-ons causes additional costs per life-years gained from \$19,945 to \$21,701

BMC, intensive patient management; DMP, disease management program; MC, multidisciplinary care; UC, usual care; QALY, quality-adjusted life-year.

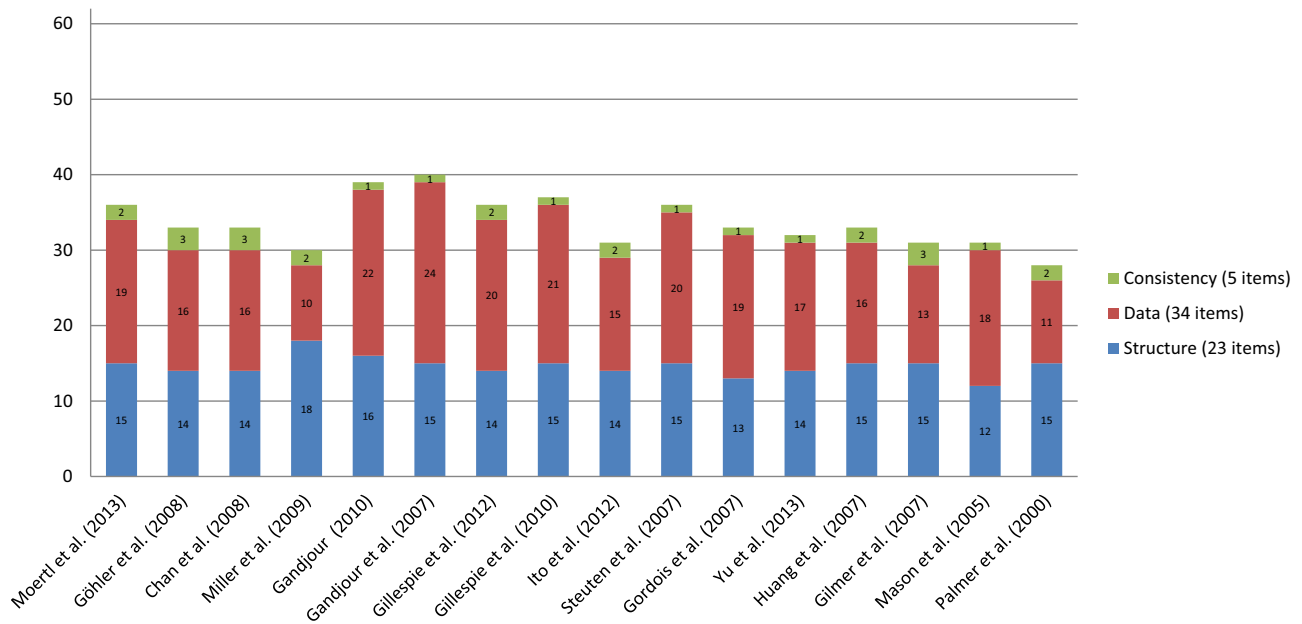


Fig. 2 – Philips quality appraisal—absolute numbers of fulfilled items.

were detected in the studies, and we illustrate them with examples for clarity. First, outdated data were used. For example, two studies [23,32] of chronic heart disease used data for stroke that were originally collected in 1976 [41]. Second, data were based on a small sample size. For instance, interviews with 74 patients with atrial fibrillation [42] were used by the same two studies [23,32]. Third, data extraction from original studies was

often opaque. One study [30] of diabetes used a mean utility score of 0.5 for poststroke, although the value in the study the work referenced [43] estimated a mean utility score of 0.45 for major stroke. Fourth, data were incorporated into the models estimated with different instruments and different methods. For example, one study [28] of diabetes derived the utility values from several sources, and in addition to the different instruments (e.g., the

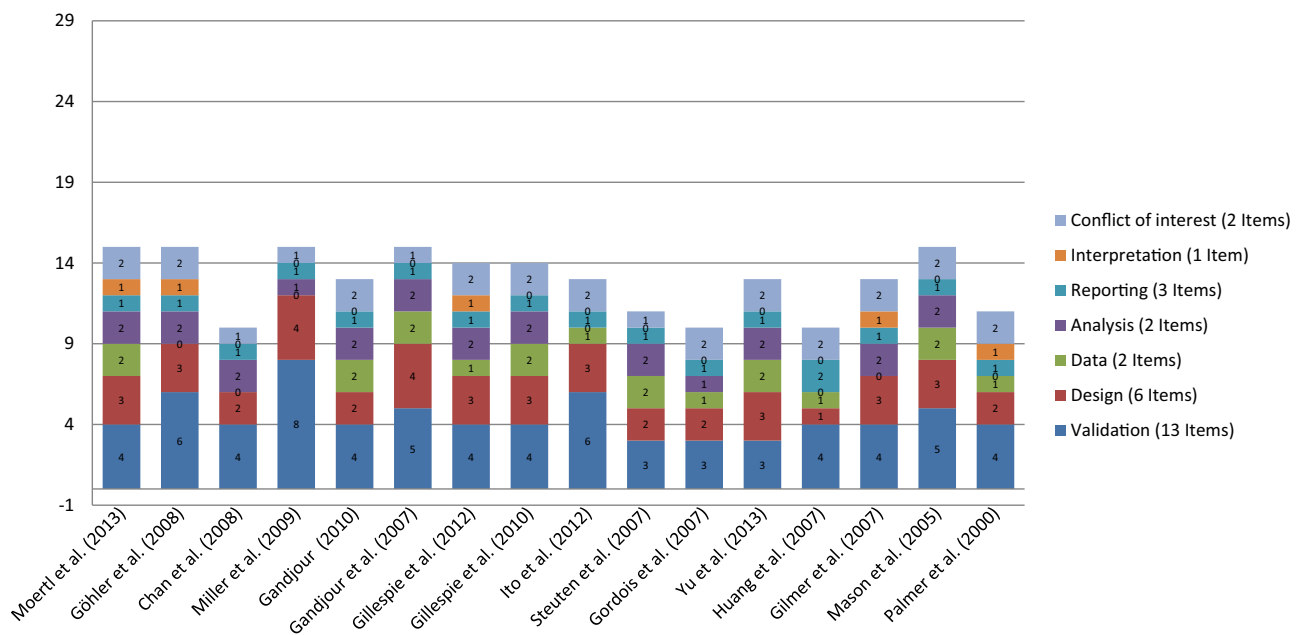


Fig. 3 – Caro quality appraisal—absolute number of fulfilled items.

EuroQol five-dimensional questionnaire or Karnofsky performance status) used to obtain the utilities, different methods (standard gamble [SG] and time trade-off [TTO]) were used to evaluate the different health states. The mean quality weights for SG, TTO, and the rating scale differed considerably: the utility was the highest measured with SG, followed by TTO and visual analogue scales [44,45]. Fifth, there were inconsistencies in the transfer of utility values. In one study [17] of chronic heart disease, the transformation for the values in the baseline group was based on the short form 12 health survey tariff [46] instead of the questionnaire used in the clinical trial (six-dimensional health state short form) [47]. These findings suggest that the selection of data was poor.

Cost of illness

The highest absolute differences in costs used by the models were found in hospitalization and medication costs and in incorporated costs for comorbidities caused by the initial disease. These categories may also be the main cost drivers in the models. Otherwise, it was not possible to standardize the costs used; therefore, an adequate interpretation cannot be made. Standardized reporting would lead to greater transparency and make the useful estimation of input parameters possible.

Sensitivity of parameters

The results of the 13 univariate sensitivity analyses indicated that a higher potential bias should decrease the differences between the models in the effectiveness of the intervention/transition probabilities, time horizons, utility values, discount rates, simulated population, costs of the DMP, and duration of the treatment effect.

Funding

It was difficult to assess whether funders tried to influence study results or at least tried to prevent the publication of unfavorable results. Nevertheless, a closer look at the four industry-funded publications [24,27,29,30] and the four studies without a conflict of interest statement [18,20,22,23] indicates that the industry-funded studies were more likely to report worse cost-effectiveness ratios. It seems that the industry's interest is the greatest in diabetes, where 60% of the models were industry-funded compared with 11% for chronic heart disease and 0% for asthma. Overall, the interest of the industry in DMPs may not be as pronounced as in pure pharmacoeconomic evaluations.

Limitations

The search was limited to the databases PubMed, MEDLINE, EconLit, and Embase. Only studies in English and German were considered. Data extraction and determining the intensity rating of the DMP and usual care were conducted by only one reviewer; therefore, errors cannot be completely ruled out. The classification of the DMPs and usual care as high, medium, and low intensity was pragmatic and did have a sound theoretical basis. The quality assessment with two different quality appraisals was conducted by two researchers; thus, single items may have been interpreted differently from the initial meaning according to the similar background of the researchers. To make the study results comparable, the gross domestic product index of the Organisation for Economic Co-operation and Development was used, and all prices were inflated to the year 2011, although this might not reflect the price increase in the health care sector adequately. The results in this review are based on published full-text articles, online supplements, and appendices without additional communication with authors or requested technical modeling

reports. Furthermore, the Markov models were not available to gain deeper insight. Nonetheless, we believe that our work provides a valuable review of recent economic models for DMPs that can be used as reference for future research.

Comparison with Literature

Only two studies [10,48] reviewed the economic evaluations of DMPs with decision-analytic modeling studies, and both were conducted for chronic heart disease. Maru et al. [10] reviewed 10 models, 8 of which were Markov models. Four studies reported an incremental cost-effectiveness ratio of more than \$50,000, six less than \$50,000, and six were dominant. For study quality assessment, two more generic tools were used, namely, the grading system for the quality of cost-effectiveness studies [49] and the Consolidated Health Economic Evaluation Reporting Standards checklist [50]. Six [16,17,20,26,29,30] of these models met the inclusion criteria for this review and were included. Göhler et al. [48] reviewed the modeling approach of 34 models estimating the cost-effectiveness of health technologies for CHF, but neglected the cost-effectiveness itself. For quality assessment, they used their own framework to assess the studies systematically and synthesize the methodological approaches. Three [18,20,21] of these models evaluated disease management interventions and were included in this review. The number of publications, however, is still low; no models for DMPs in chronic obstructive pulmonary disease or breast cancer were found. We hope that modelers will contribute to fill these gaps in research soon.

Conclusions

Fourteen studies reported QALYs and two studies reported LYG as outcome measures. For QALYs, 11 out of 14 studies reported at least one result for a DMP less than \$50,000 per QALY (seven [16,17,21,23,29,32] [18] out of nine studies of chronic heart disease, two [22,25] studies of asthma, and all three [24,28,30] of diabetes). For LYG, both studies reported costs less than \$30,000 per LYG ([26,27] both of diabetes). According to the quality assessment, however, weaknesses in the models were found, namely, reporting practice and selection of input data. Although journals have space and word limits, the reporting practice could be standardized easily by using technical and online appendices [10]. In addition, a systematic review of the literature should be conducted, at least for the most important parameters.

The choice of the quality appraisal used to assess the quality of studies and models in a review may influence its results, shown here by the low value of the Spearman rank correlation coefficient, indicating no correlation between the two instruments.

Because most of the models merely extrapolate the results of a clinical trial, the models are relatively static and the incremental effects of individual components of the DMPs cannot be evaluated economically.

In all indication areas, the disease and its progression are represented well by the model structures. Although there are variations between the models within an indication, these are small and unlikely to influence the results substantially.

For the incorporated data in the models, the picture is different. Utility weights, time horizons, costs, and the control group treatment program or its description vary considerably and may affect the results in either direction.

If these problems are addressed, then Markov models should be more suitable to evaluate economic effects of multicomponent interventions, and provide helpful information for decision makers.

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Supplemental Materials

Supplemental material accompanying this article can be found in the online version as a hyperlink at <http://dx.doi.org/10.1016/j.jval.2016.07.004> or, if a hard copy of article, at www.valueinhealthjournal.com/issues (select volume, issue, and article).

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