BMJ Open Diabetes Research & Care

National health and economic impact of a lifestyle program to prevent type 2 diabetes mellitus in Germany: a simulation study

Katherine Ogurtsova [1,2,3], Michael Laxy,[1,4] Karl Emmert-Fees,[1,4] Charalabos-Markos Dintsios,[5] Ping Zhang,[6] Andrea Icks[1,3,7]

To cite: Ogurtsova K, Laxy M, Emmert-Fees K, *et al*. National health and economic impact of a lifestyle program to prevent type 2 diabetes mellitus in Germany: a simulation study. *BMJ Open Diab Res Care* 2024;**12**:e004382. doi:10.1136/bmjdrc-2024-004382

► Additional supplemental material is published online only. To view, please visit the journal online (https://doi.org/10.1136/bmjdrc-2024-004382).

Received 5 June 2024
Accepted 26 September 2024

Check for updates

For numbered affiliations see end of article.

Correspondence to
Dr Katherine Ogurtsova; katherine.ogurtsova@hhu.de

ABSTRACT

Introduction To examine the long-term health and economic impact of a lifestyle diabetes prevention program in people with high risk of developing type 2 diabetes in Germany.

Research design and methods We assessed the lifetime cost-effectiveness of a 2-year pragmatic lifestyle program for preventing type 2 diabetes targeting German adults aged 35–54 and 55–74 years old with hemoglobin A1c (HbA1c) from 6.0% to 6.4%. We used the Centers for Disease Control and Prevention RTI Diabetes Cost-Effectiveness Model to run a simulation on the program effectiveness. We estimated incremental health benefits in quality-adjusted life years (QALYs) and costs using an established simulation model adapted to the German context, from a healthcare system and societal perspective. The cost-effectiveness of the program was measured by incremental cost-effectiveness ratios (ICERs) in cost per QALY. We projected the number of type 2 diabetes cases prevented by participation rate if the program was implemented nationwide.

Results The lifestyle program would result to more QALYs and higher costs. The lifetime ICERs were 14 690€ (35–54 years old) and 14 372€ (55–74 years old) from a healthcare system perspective and cost saving (ICER=−3805€) and cost-effective (ICER=4579€), respectively, from a societal perspective. A total of 10 527 diabetes cases would be prevented over lifetime if the program was offered to all eligible people nationwide and 25% of those would participate in the program.

Conclusions Implementing the lifestyle intervention for people with HbA1c from 6.0% to 6.4% could be a cost-effective at standard willingness to pay level strategy for type 2 diabetes prevention. The intervention in the younger cohort could be cost saving from a societal perspective. The successful implementation of a lifestyle-based diabetes prevention program could be an important component of a successful National Diabetes Strategy in Germany.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Population-based lifestyle intervention programs to prevent type 2 diabetes have been implemented in many countries like the USA and United Kingdom while such a program is still under debate in Germany.

WHAT THIS STUDY ADDS

⇒ We estimated the long-term health and economic impact if a lifestyle program was put into action on a large scale from a healthcare payer and societal perspective in Germany and found that such a prevention program could prevent several thousand cases of type 2 diabetes and be cost-effective.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Implementing lifestyle intervention programs among people with high risk of type 2 diabetes in Germany may be an efficient use of healthcare resources.

INTRODUCTION

Results from clinical trials and translation studies in real-world settings show that type 2 diabetes can be prevented or delayed by lifestyle interventions in individuals with increased risk of type 2 diabetes.[1] Those lifestyle interventions were also found to be cost-effective or even cost saving[2] from a healthcare system perspective in many countries. A recent systematic review of trial-based studies demonstrated that various interventions to prevent type 2 diabetes in high-risk populations were both cost-effective and feasible in diverse settings.[3] The gap between gold-standard results shown in trials and effectiveness in everyday practice is usually addressed in pragmatic studies designed to be practical and applicable in real-world clinical settings. Such pragmatic lifestyle programs have been successfully established in the routine practice in some Western countries[4–7] and there is robust real-world evidence that these programs are effective in lowering weight and hemoglobin A1c (HbA1c) if implemented in practice.[8] The systematic review on the effectiveness of pragmatic lifestyle interventions for preventing type 2 diabetes found that these interventions led to weight loss, and adherence to guidelines was significantly associated with greater weight loss.[9] A quasi-experimental evaluation of a nationwide diabetes prevention program, utilizing electronic health records from over 2 million patients, provided causal evidence of improved glycemic control and reduced risk factors in the behavior change program for prediabetes.[8] A systematic review found that lifestyle interventions targeting high-risk individuals were generally cost-effective for preventing type 2 diabetes from a healthcare system or societal perspective.[2]

In the USA, the National Diabetes Prevention Program (US-NDPP) was authorized by the US Congress in 2010 and since then has been delivered by over 1500 organizations, reaching almost 300 000 people.[4] The British National Institute for Health and Care Excellence (NICE) recommends a lifestyle intervention for individuals with intermediate categories of hyperglycemia for preventing type 2 diabetes,[5 6] and the National Health Service (NHS) England launched the NDPP (NHS-NDPP) in 2016[6 10] into significant health benefits for participants.[8] In Germany, several programs have been recommended.[11] However, to date, no such program was put into action.

Whether a national program like those in the USA and the UK would be a good use of healthcare resources in Germany is unknown. Evidence from the USA or the UK may not be directly applicable to Germany due to two main reasons. First, the population characteristics of people at high risk of developing type 2 diabetes might differ. Second, the costs for treating diabetes and its complications are highly context-specific and country-specific. In German setting, the lifestyle programs of diabetes prevention were evaluated in a handful of studies.[12–15] These studies either overlooked diabetes complications[12 13] or primarily focused on weight management, without directly estimating the impact of lifestyle interventions on diabetes incidence.[14 15] Furthermore, previous studies often ignored productivity losses and evaluated those programs from a narrow healthcare system perspective and did not consider potential heterogeneity in the cost-effectiveness across the age range.[2] Without that, both the societal value of these programs as well as the target populations with the most favorable cost-effectiveness ratio remain unknown.

In this study, we aim to examine the long-term health and economic impact of a pragmatic lifestyle program, as successfully implemented in large scale in other countries, for Germany from a healthcare payer and societal perspective. We also examine how the effectiveness and cost-effectiveness of the lifestyle program to prevent type 2 diabetes vary by age group at both individual and population levels.

METHODS AND MATERIALS

Evaluation approach

We used an established and validated diabetes simulation-model,[16] adapted it to the German context, and simulated the lifetime cost-effectiveness of a lifestyle diabetes prevention program from a healthcare system and societal perspective. The healthcare system perspective included only direct medical costs. The societal perspective also included patient-time costs associated with diabetes self-management (direct non-medical costs) and productivity losses (indirect costs). We also projected the population-level impact of a nationwide implementation of the program, under different theoretical levels of participation in the eligible population. The workflow of the analysis is shown in online supplemental file 1, figure 1 .

Intervention

The lifestyle intervention programs evaluated were based on the recommendation of NICE public health guidelines (PH38) and programs being implemented in the NHS-NDPP program.[6] The program targeted individuals with a high risk of developing type 2 diabetes (HbA1c at range 6.0%–6.4% or 42–46 mmol/mol) who were identified during a routine check-up. The program includes a core component of 13 group education sessions in the first year followed by seven maintenance sessions over the following 2 years. The program covers topics like diabetes risk assessment and risk identification, physical activity, weight management, dietary advice, and medications, with an annual review by a general practitioner and blood tests.[6 7]

Simulation model

We used the Centers for Disease Control and Prevention (CDC) RTI Diabetes Cost-Effectiveness Model (CDC-RTI DM), an established and validated Markov cohort model designed to simulate the development and progression of type 2 diabetes and to assess the cost-effectiveness of various prevention and treatment interventions including diabetes and intermediate hyperglycemia screening. The model is described in detail elsewhere.[16] In brief, the model simulates disease progression based on annual transitions of multiple disease states. It follows cohorts of patients to either death or 95 years of age, simulating the development of diabetes-related complications on three microvascular disease paths (nephropathy, neuropathy, and retinopathy) and two macrovascular disease paths (coronary heart disease and stroke). This model is closed, namely starts with a fixed population that is followed over time without any new subjects that can enter or leave the study at different times. The model outcomes include lifetime development of diabetic complications (nephropathy, neuropathy, retinopathy, coronary heart disease and stroke), diabetes-related healthcare costs, life years, and quality-adjusted life years (QALYs) gained. The model was internally and externally validated[17] and has been used extensively in different cost-effectiveness

BMJ Open Diab Res Care 2024;12:e004382. doi:10.1136/bmjdrc-2024-004382

analyses in the USA context.[18–20] Details of the simulation model are described in a technical report in online supplemental file 2.

For this analysis, the CDC-RTI DM was modified to fit the German setting. We parametrized the model using the best available German-specific data, or international data if no German source was found. We relied on prospective German studies to assess the epidemiologic parameters as well as statutory health insurance (SHI) claims data to assess the cost parameters. After adaptation, we validated the model in parts (all-cause cumulative mortality, cumulative mortality of coronary heart disease, and stroke) as recommended in the principles of good practice for modeling in healthcare evaluation.[21] Extensive information on parameters, data sources, assumptions, and limitations is provided in online supplemental file 1 and in online supplemental file 4.

Key parameters of the simulation model

The key model parameters required in the analysis are presented in online supplemental file 1, table 1.

Effectiveness of the lifestyle intervention program: the effectiveness of the program on reducing type 2 diabetes incidence (the relative risk of diabetes in participants undertaking a pragmatic lifestyle program) was based on data from a recent meta-analysis.[22] We conservatively assumed that the program causes an effect only on type 2 diabetes incidence and do not affect a disease progression, the effect of the program is the same for all subgroups and that the effect held only during the program and would be marginalized after the program stopped. Furthermore, we assumed that adherence of participants was equivalent to that seen in the pragmatic real-world intervention studies from which relative risk reduction was derived.[22]

Costs of the lifestyle intervention program: the cost of the program was taken from Roberts *et al*[7] and converted to Euros by applying a purchasing power parity (PPP) conversion based on 2015 values. This covered staff costs, including a social security contribution, and blood test costs. For validation, we also calculated the program costs bottom-up using German prices per service. As both approaches returned similar results (not shown), we utilized only the PPP-converted costs in this analysis.

Health utilities

Health utility decrements associated with diabetes and diabetes complications were taken from a large population-based German study (see online supplemental file 1, table 2).[23]

Cost parameters

Direct medical cost of diabetes and complications

The yearly baseline medical cost for a patient with and without diabetes as well as excess costs related to risk factors or diabetes complications were taken from Kähm *et al* who used a panel data approach based on German claims data of an SHI to estimate the excess costs of diabetes complications.[24] Annual costs of medical care for a patient with intermediate hyperglycemia were calculated using the age-adjusted and sex-adjusted cost ratio of ‘intermediate hyperglycemia’ versus ‘no diabetes’ taken from a population-based cohort study in southern Germany.[25] The multiplicative cost approach was used in the simulation.[26]

Direct non-medical costs for diabetes care

The patient time costs due to diabetes self-management were taken from Icks *et al*[27] where time spent on self-management activities was assessed using a validated questionnaire, categorized as lost leisure time, and valued with a mean adjusted net wage per hour in Germany. The intervention-related direct non-medical costs (cost for exercise classes and equipment, food and food preparation items, and transportation) were not included in the analysis because no reliable information on such costs is available.

Indirect societal costs (productivity losses)

The costs of productivity loss according to the human capital approach were taken from Ulrich *et al*.[28] The costs were due to losses in productivity such as sick days and long-term incapacity to work. These indirect societal costs were restricted to the age group <65 years old. The costs due to unpaid work, presenteeism or premature death were not considered.

In the analysis, the cost-effectiveness was calculated from two perspectives: (1) a healthcare system perspective that only included direct medical costs, (2) a societal perspective that included direct medical, non-medical costs (the patient time costs), and indirect societal costs.

Simulation population

The baseline population consisted of two cohorts of persons aged 35–54 and 55–74 with newly diagnosed intermediate hyperglycemia (HbA1c at range 6.0%–6.4% or 42–46 mmol/mol). The characteristics and the distribution of the initial cohort by age, sex, smoking habits, hypertension, and high cholesterol status were estimated from the Cooperative Health Research in the Region of Augsburg (KORA) S4 study, a population-based study from southern Germany covering individuals 25–74 years of age.[25]

Cost-effectiveness of the program and thresholds for adoption

We estimated the incremental cost-effectiveness ratios (ICER) in €/QALY by dividing the discounted incremental cumulative costs by the discounted incremental QALYs. All costs were adjusted to 2020 values and future costs and QALYs were discounted by an annual discount rate of 3.5%, which is recommended by NICE.[29]

In Germany, no explicit willingness-to-pay (WTP) is defined[30]; we, therefore, assessed the probability that the intervention is cost-effectiveness at the following WTP thresholds: of 20 000 €/QALY corresponding to the NICE recommendations,[31] 50 000 €/QALY

Table 1 Lifetime incremental effectiveness, incremental cost and cost-effectiveness of implementing a lifestyle type 2 diabetes prevention program, by age group and study perspective

	Reference (no intervention)	Intervention
35–54 years		
Total costs (€, 2020), healthcare system perspective*	62 793.71	62 958.95
Total costs (€, 2020), societal perspective†	66 553.68	66 510.88
Total QALYs	13.37	13.39
Costs vs no intervention (€, 2020), incremental, from healthcare system perspective*		165.24
Effect vs no intervention (QALYs), incremental, from healthcare system perspective*		0.01
Costs vs no intervention (€, 2020), incremental, from societal perspective†		−42.80
Effect vs no intervention (QALYs), incremental, from societal perspective†		0.01
Incremental cost-effectiveness ratios (ICER) (relative to no intervention) (€/QALY) from a healthcare system perspective		14 689.76
ICER (relative to no intervention) (€/QALY) from a societal perspective		−3,804.53
Cumulative incidence of type 2 diabetes at the end of the simulation (%)	21.05	20.61
The average number of years lived with type 2 diabetes at the end of the simulation, in years	6.64	6.15
55–74 years		
Total costs (€, 2020), healthcare system perspective*	46 566.27	46 787.15
Total costs (€, 2020), societal perspective†	48 504.45	48 574.81
Total QALYs	8.92	8.93
Costs vs no intervention (€, 2020), incremental, from healthcare system perspective*		220.88
Effect vs no intervention (QALYs), incremental, from healthcare system perspective*		0.02
Costs vs no intervention (€, 2020), incremental, from societal perspective†		70.36
Effect vs no intervention (QALYs), incremental, from societal perspective†		0.02
ICER (relative to no intervention) (€/QALY)		14 372.40
ICER (relative to no intervention) (€/QALY) from a societal perspective		4578.17
Cumulative incidence of type 2 diabetes at the end of the simulation (%)	16.77	16.10
The average number of years lived with type 2 diabetes at the end of the simulation, in years	8.76	8.16

*Includes direct medical costs only.
†Includes direct medical costs, indirect societal costs and direct non-medical costs.
QALYs, quality-adjusted life years.

corresponding to Neumann *et al*,[12] and 100 000 €/QALY as a maximum value. We also estimated the WTP needed to achieve a probability of cost-effectiveness more than 50%, 75%, and 95% based on cost-effectiveness acceptability curves (CEACs), which show the probability that an intervention is cost-effective at different WTP values.

We also compared the cumulative incidence of type 2 diabetes, the average number of years lived with type 2 diabetes in both intervention and routine care groups, and the number of avoided type 2 diabetes cases.

Sensitivity analysis

In the univariate sensitivity analysis, we checked the robustness of the results by broadly considering a range of percentages for the costs of the intervention (50% to 150%), the baseline medical costs (80% to 120%), and the program effect on type 2 diabetes incidence (50% to 150%). In the probabilistic sensitivity analysis (PSA), we simultaneously varied intervention costs and effects on type 2 diabetes incidence of the intervention. This approach accounts for decision uncertainty by considering a multiplier for intervention costs (uniformly distributed between 0.5 and 1.5) and assuming Gamma and log-normal distributions for baseline medical costs and effect relative ratios, respectively. We performed 1000 iterations to compute cost-effectiveness and analyzed the distribution of cost-effectiveness ratios including the mean, median, credible intervals, and probabilities to achieve different WTP thresholds.

The PSA was performed only from the healthcare system perspective because of the software limitations.

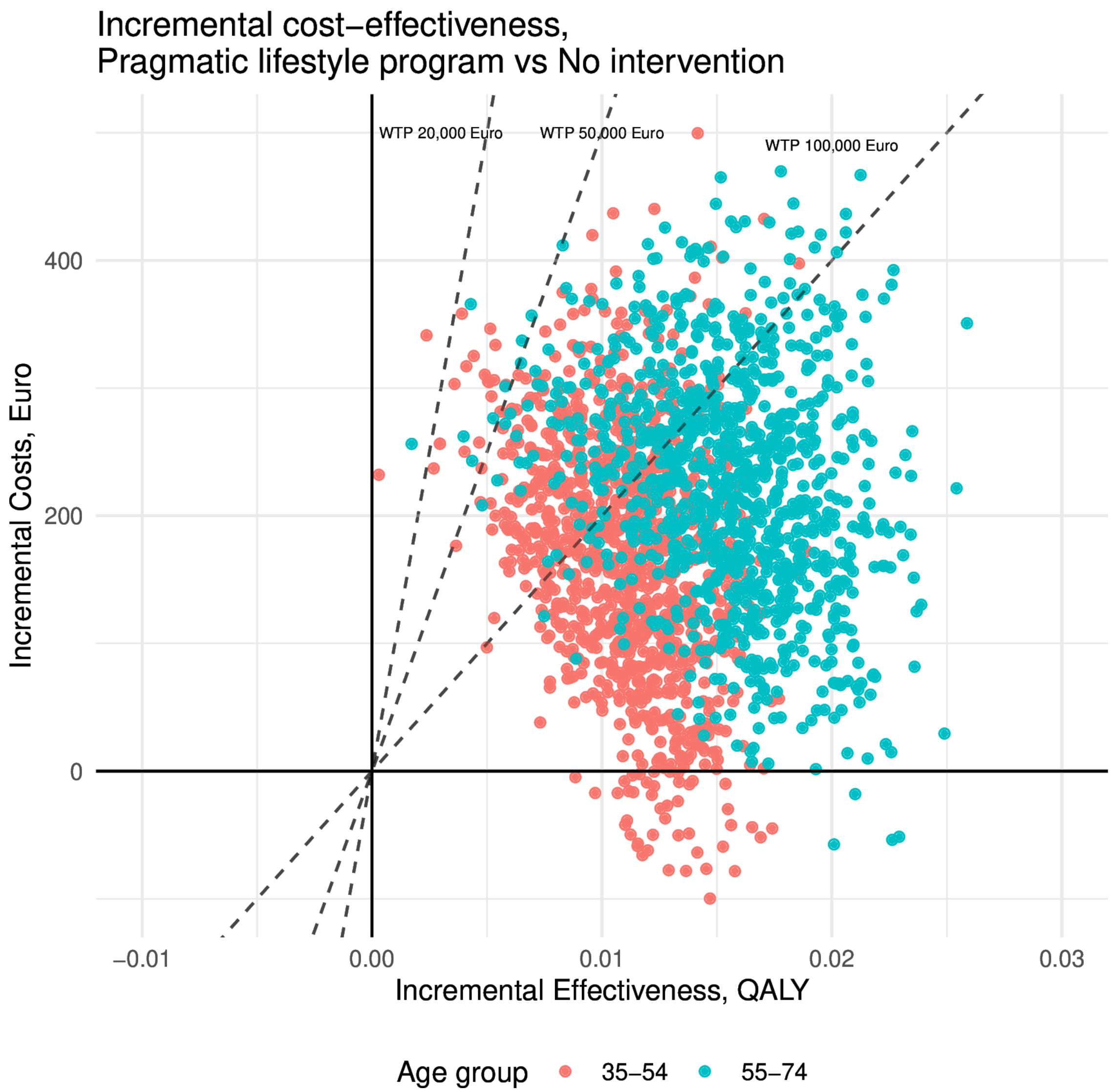

Figure 1 Cost-effectiveness plane: incremental cost and QALYs relative to no intervention in the probabilistic sensitivity analysis. QALYs, quality-adjusted life years.

The statistical analysis and graphs were performed in R V.4.4.1.

To report the results, we followed the recommendations of the Consolidated Health Economic Evaluation Reporting Standards (CHEERS) (see online supplemental file 3).

Population-level analysis

In view of the high public health significance of diabetes prevention and the relevance of informing decision-making, we analyzed the effect of a nationwide diabetes prevention program also at population level in Germany. We focused on the affected German population, namely persons with intermediate hyperglycemia, as a target group of the program. We assumed that the program would be offered to a patient at risk by a general practitioner. In Germany, 45% of patients participated in a disease-related training after a clinician's recommendation.[32] In this analysis, we assumed five scenarios where population proportions of participation in the nationwide program were 5%, 10%, 25%, 50% or 100% of all individuals with intermediate hyperglycemia to reflect a full range of the theoretical and expected participation. We estimated a reduction in type 2 diabetes incidence, average number of years lived with diabetes, and total costs of the program over lifetime. The simulation was based on two closed cohorts (35–54 and 55–74 years old) followed from starting age to the death.

RESULTS

Cost-effectiveness of the program at individual level

The lifetime costs and QALYs for both intervention and non-intervention groups as well as resulting ICERs are shown in table 1. The cost-effectiveness planes are shown in figure 1. In all analyses, the lifestyle program led to a gain in QALYs and an increase in costs. The ICERs for the lifestyle intervention program were 14,690€ per QALY gained for the 35–54 years olds and 14,372€ per QALY

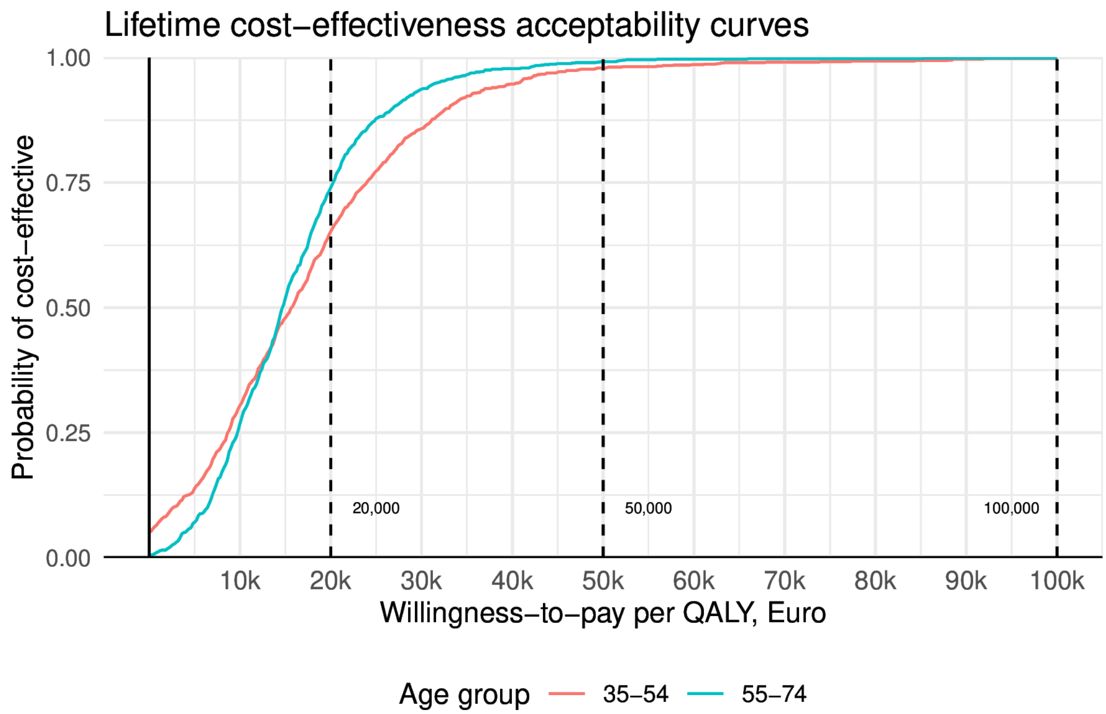

Figure 2 Lifetime cost-effectiveness acceptability curves from a healthcare system perspective. QALYs, quality-adjusted life years.

gained for the 55–74 years olds from a payer's perspective over lifetime. From a societal perspective (including indirect societal costs and direct non-medical cost) the intervention costed −3,805€ per QALY gained for 35–54 year olds and 4,579€ for 55–74 year olds, and dominated the comparator in the younger cohort (was more effective and cost saving). The main driver for cost savings from a societal perspective was the patient time costs (online supplemental file 1, table 7).

Diabetes-related outcomes

The intervention led to a lower cumulative incidence of type 2 diabetes (20.61% vs 21.05%) at the end of the simulation for the 35–54 years old cohort and a lower number of years lived with type 2 diabetes (0.03 years reduction per person in the same scenario) (online supplemental file 1, table 3). The effect was more pronounced after 10 years than at the end of the simulation. The relative risk reduction (the proportion of prevented type 2 diabetes cases) was higher at 10 years then at the end of the simulation. For the older participants, the health benefit in reducing diabetes incidence is greater. We found no significant changes in the incidence of type 2 diabetes complications or any direct effect on all-cause mortality. However, the onset of complications and mortality was slightly postponed to older ages (not shown).

Sensitivity analysis

The distribution of incremental costs, incremental effects, and cost-effectiveness ratios from PSA is shown in online supplemental file 1, table 4. The CEACs are shown in figure 2, and the probabilities of the intervention to be cost-effective at different WTP thresholds are shown in online supplemental file 1, table 5. At a WTP threshold of 20 000 €/QALY, 50 000€/QALY and 100 000€/QALY, the probability of the intervention to be cost-effective is 65.4%, 98.0%, and 99.8% in 35–54 year olds and 74.0%, 99.2% and 99.9% in 55–74 year olds from a healthcare system perspective over lifetime.

The WTP thresholds needed to achieve a probability ≥50% of cost-effectiveness based on CEACs ranged from 14730 to 15 603 €/QALY. To achieve a probability of cost-effectiveness ≥95%, a WTP of 40390 to 31 745 €/QALY would be necessary.

Key factors impacting cost-effectiveness calculations in the sensitivity analysis were relative risk reduction of type 2 diabetes, costs of the interventions, and baseline medical costs (online supplemental file 1, table 6 and figure 2).

Population-level analysis

The absolute number of prevented or delayed cases, accumulated QALYs, and costs would depend on the fraction of the population participating in the program (table 2). The absolute numbers of diabetes cases are shown in online supplemental file 1, table 8.

If the program was offered to everyone with diagnosed intermediate hyperglycemia in both age groups in Germany (~8.5 million people) and if 25% of those participated in the program, around 10500 incident cases of type 2 diabetes (2.5% in relative terms) would be avoided and around 35200 QALYs would be gained over a lifetime perspective. The discounted lifetime cost of the program would be around 1 08 517 million € from

Table 2 Estimated aggregated health outcomes and costs of implementing a nation-wide diabetes prevention program in Germany

Population at high risk of developing type 2 diabetes		Lifetime reduction in incident cases of type 2 diabetes, cases	Lifetime reduction in incident cases of type 2 diabetes, %	Lifetime reduction in the average number of years lived with type 2 diabetes, years	Lifetime reduction in the average number of years lived with type 2 diabetes, %	Upfront cost in the first 2 years of implementing the program (€, 2020)	Lifetime total costs of from a healthcare system perspective (€, 2020)	Lifetime incremental costs from a healthcare system perspective (€, 2020)	Lifetime total costs from a societal perspective (€, 2020)	Lifetime incremental costs from a societal perspective (€, 2020)	Lifetime incremental QALYs
Total N	Mean % of participating										
Cohort 35–54 years											
2 308 625	100%	26 788	2.06	0.03	0.65	745 559 616	145 348 605 401	381 475 867	588 466 202 230	–98 799 116	32 321
1 154 312	50%	13 394				372 779 646	72 674 271 221	190 737 851	294 233 101 115	–49 399 537	14 572
577 156	25%	6 697				186 389 823	36 337 135 611	95 368 926	147 116 598 239	–24 699 768	6889
230 862	10%	2 679				74 555 800	14 534 829 061	38 147 504	58 846 620 223	–9 879 890	2660
115 431	5%	1 339				37 277 900	7 267 414 530	19 073 752	29 423 262 431	–4 939 945	1314
Cohort 55–74 years											
6 170 870	100%	15 319	3.96	0.06	0.93	1 967 541 011	288 717 395 540	1 363 007 102	298 897 291 524	434 170 950	168 359
3 085 435	50%	7 660				983 770 505	144 358 697 770	681 503 551	149 448 581 027	217 085 475	65 799
1 542 718	25%	3 830				491 885 412	72 179 372 279	340 751 886	74 724 290 514	108 542 773	28 304
617 087	10%	1 532				196 754 101	28 871 739 554	136 300 710	29 889 664 418	43 417 095	10 219
30 854	5%	766				98 376 891	14 435 846 383	68 150 245	14 944 832 209	21 708 512	4 926

QALYs, quality-adjusted life years.

a healthcare system perspective and 113 324 million € from a societal perspective. The upfront budget impact of delivering the intervention in the first 2 years would be 678 million €.

DISCUSSION

This study is the first to comprehensively examine the long-term cost-effectiveness of introducing a program to prevent type 2 diabetes targeting individuals with intermediate hyperglycemia in Germany. Furthermore, it adds to previous economic evaluations by quantifying the potential impact in two age groups and by two different perspectives (healthcare system and societal) as well as by estimating the potential costs and consequences at the level of a Germany-wide program.

Neumann *et al* estimated the long-term cost-effectiveness of a hypothetical lifestyle intervention program for the prevention of type 2 diabetes using a four-state Markov model in Germany.[12] However, that model did not account for diabetes complications and their costs and did not allow extrapolating the results on a population level.

Only a few studies compared younger and older cohorts in cost-effectiveness analysis, mostly focusing on diabetes screening.[33] Furthermore, many other cost-effectiveness analyses ignored indirect societal costs and direct non-medical costs, although it is known from cost of illness studies that those are substantial.[27 28]

Our main results are comparable with previous international studies, for example, in the UK and the USA.[4–6] A recent systematic review evaluating programs to prevent type 2 diabetes reported a median ICER of 13 761 $/QALY (12 653 €/QALY), which is in the same range as our results. While ICERs in each varied between studies, all but one showed ICERs far below the commonly used WTP threshold (US$ 50,000).[34]

In our study, the intervention in the older group had a higher probability of being cost-effective from the healthcare system perspective compared with the younger group, which agrees with Neumann *et al*.[35] However, from a societal perspective, the intervention in the younger cohort led to lower ICERs and even became cost saving, as the extra productivity losses were only attributed to the under-65 group in our method, so the costs of the diabetes case were higher for them. In the younger group, the effect is more pronounced since this cohort lives longer with diabetes. We showed ICERs for different cost structures, highlighting that it is essential to include direct non-medical and indirect societal costs in the evaluation of population-wide programs to understand their full impact and to avoid underestimation of benefits. In our simulation study, we adapted the CDC-RTI DM to the German setting and relied on the best available German-specific and international data. We also showed the potential cost-effectiveness of a pragmatic lifestyle intervention scaled up to the total population at risk of developing diabetes, which had been done for the USA[36] and the UK,[7] but not for Germany. This population-level analysis shows that if 25% of people with a HbA1c of 6.0%–6.5% (~2 million people) would participate in the program, one could prevent 10 500 incident cases and gain 35 200 QALYs from a societal perspective over their lifetime. However, such a scenario would come with substantial upfront investments of around 678 million €, which is almost 1.5% of the annual healthcare expenditure for diabetes in Germany.[37] In light of around 0.5 million incident cases of diabetes that occur in Germany annually, this highlights that high-risk individual-level prevention strategies as analyzed in this study need to be complemented with population-level policies and interventions that address the upstream determinates of obesity and type 2 diabetes.[38–41] Moreover, patient participation in the lifestyle interventions for individuals at risk of diabetes varied from 15% to 80%,[42] so our assumption might be considered conservative.

There are strengths and weaknesses of our study. Our strengths included that we used a well-established simulation model for modeling prevention of type 2 diabetes. We parameterized it with epidemiological and economic inputs from German studies that were based on large population-based cohorts or population-representative health insurance claim data. Also, we performed PSA. This analysis, though limited to the healthcare perspective due to software constraints, provides a more comprehensive picture of cost-effectiveness uncertainty compared with univariate analysis.

Our first limitation was that assumptions were required for our simulation analysis. However, we purposely made our assumptions conservative. For example, it is unknown if and how lifestyle programs affect the probability of developing type 2 diabetes beyond the active program phase. We assumed no preventative effect beyond the active program phase. Other assumptions include no reversion from intermediate hyperglycemia to normoglycemia, the same utilities in both intervention and routine care scenarios, adherence equivalent to those in real-world setting studies, etc. A detailed discussion of these assumptions is given in online supplemental file 1.

Our study is also subjected to typical limitations of all simulation studies: dependence on a model structure and parameters. Moreover, not all primary clinical data used in the model are available for Germany; some had to be taken from other countries. The baseline population in the model was parameterized based on the KORA S4 study, a large population-based cohort. KORA was conducted specifically in the Augsburg region, which may not fully represent the entire German population and may not capture all demographic variations across Germany. Regional differences in health outcomes have been observed between northeast and south Germany. Also, the study covers a wide adult age range but does not include very young or very old populations.

We did not include individuals aged 75 and older in our analysis, even though this demographic is growing and increasingly plays a crucial role in national health systems. Assessing the potential effect of the pragmatic lifestyle intervention on this population would indeed be a valuable contribution. However, we chose not to include individuals over 75 years at baseline for two reasons. First, most trial evidence on the effectiveness of lifestyle interventions focuses on individuals younger than 75. Second, our simulation was based on the baseline cohort characteristics from the KORA S4 study, which only includes individuals up to 75 years old. We lacked population-based data on the distribution of risk factors (such as smoking habits, hypertension, and high cholesterol) for those older than 75, which is why they were excluded from our analysis.

Another limitation is that our study did not include program implementation expenses. Moreover, we adopted the costs of the diabetes prevention program directly from Roberts *et al*,[7] which might pose some questions on the transferability as medical care systems and budgeting differ between the UK and Germany. The costs of pragmatic lifestyle interventions varied widely depending on what was included in the program; however, we appointed the program recommended by NICE,[6 7] suggesting that the total costs of such a program depend only on the costs of its components in a particular healthcare system. Alternatively, the costs could be taken from another intervention implemented in Germany. Due to the limitations of a Markov model structure, we also could not calculate the loss of productivity due to premature death or identify the largest driver in indirect societal diabetes costs. Unfortunately, no cost structure for any such intervention was found in the literature. However, considering the robustness of our results towards variations in our crucial model assumptions, these limitations are unlikely to change the general conclusions of our study.

In this health-economic analysis, we could not identify which component of the intervention plays the most significant role because this objective was out of scope of this study. As was shown, several key elements contribute to the effectiveness of diabetes prevention programs. The original DPP was a 3-year randomized trial followed by 7 years of modified intervention follow-up, suggesting longer term interventions are beneficial.[43] Moreover, flexible interventions delivered by skilled lifestyle coaches that accommodate individual preferences and reflect local community and cultural contexts may achieve better outcomes.[44] However, this type of investigation aligns more with the primary objectives of experimental studies.

CONCLUSION

In our simulation study, we found that a pragmatic lifestyle intervention for preventing type 2 diabetes was highly cost-effective from the healthcare system perspective across all age groups. The intervention in the younger cohort could be cost saving from a societal perspective. If the program was scaled up to a national policy level, the program would prevent more than 10 500 new type 2 diabetes cases over lifetime and need an investment of 1.5% of diabetes-related yearly healthcare expenditures in Germany.

Implementing a type 2 diabetes prevention program like the UK's NHS-NDPP in Germany would be cost-effective at standard willingness to pay levels. Next to structural upstream prevention approaches, the successful implementation of a lifestyle-based diabetes prevention could be an important component of a successful National Diabetes Strategy in Germany.

Twitter summary

This simulation study shows that a lifestyle intervention for preventing type 2 diabetes among persons with intermediate hyperglycemia in Germany would likely be cost-effective.

Author affiliations

[1]German Center for Diabetes Research, Neuherberg, Germany
[2]Institute of Occupational, Social and Environmental Medicine, Heinrich-Heine-Universitat Dusseldorf, Dusseldorf, Germany
[3]Institute for Health Services Research and Health Economics, German Diabetes Center, Leibniz Center for Diabetes Research at the Heinrich-Heine-University Dusseldorf, Dusseldorf, Germany, Düsseldorf, Germany
[4]Professorship of Public Health and Prevention, School of Medicine and Health, Technical University of Munich, Munchen, Germany
[5]Institute for Health Services Research and Health Economics, Heinrich Heine University Düsseldorf, Dusseldorf, Germany
[6]Centers for Disease Control and Prevention, Atlanta, Georgia, USA
[7]Institute of Health Economics and Health Care Management, Heinrich Heine University Düsseldorf, Dusseldorf, Germany

Contributors KO, ML, KE-F, C-MD, AI designed the study. KO performed the study. PZ was a member of the development team for the DC-RTI DM. KO, ML, KE-F, C-MD, AI interpreted the data, edited the manuscript, and contributed to discussions. KO drafted the manuscript and performed the analysis. All authors critically revised the manuscript and approved the final version to be published. KO had full access to all the data in the study and final responsibility for the decision to submit for publication. She is the guarantor of this work.

Funding The study was supported by institutional funding (German Diabetes centre) of the Federal Ministry of Health and by the Ministry of Culture and Science of North Rhine-Westphalia. It was further funded by the Federal Ministry of Education and Research as part of the German center for Diabetes Research. The KORA study (KORA, Cooperative Research in the Region of Augsburg) was initiated and financed by the Helmholtz Zentrum München—German Research center for Environmental Health, which is funded by the German Federal Ministry of Education and Research and by the State of Bavaria.

Disclaimer The funders had no role in the study design, collection, analysis, and interpretation of data, in the writing of the report, or in the decision to submit the article for publication. We confirm the independence of researchers from funders and that all authors, external and internal, had full access to all the data (including statistical reports and tables) in the study and can take responsibility for the integrity of the data and the accuracy of the analysis.The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval Not applicable.

Provenance and peer review Not commissioned; externally peer-reviewed.

Data availability statement Data are available upon reasonable request.

Supplemental material This content has been supplied by the author(s). It has not been vetted by BMJ Publishing Group Limited (BMJ) and may not have been peer-reviewed. Any opinions or recommendations discussed are solely those

ORCID iD
Katherine Ogurtsova http://orcid.org/0000-0002-3002-1916

REFERENCES

1 Galaviz KI, Weber MB, Straus A, *et al*. Global Diabetes Prevention Interventions: A Systematic Review and Network Meta-analysis of the Real-World Impact on Incidence, Weight, and Glucose. *Diabetes Care* 2018;41:1526–34.
2 Zhou X, Siegel KR, Ng BP, *et al*. Cost-effectiveness of Diabetes Prevention Interventions Targeting High-risk Individuals and Whole Populations: A Systematic Review. *Diabetes Care* 2020;43:1593–616.
3 Xiong Y, Huo Z, Wong SYS, *et al*. Cost effectiveness of nonpharmacological prevention programs for diabetes: A systematic review of trial-based studies. *Chronic Dis Transl Med* 2024;10:12–21.
4 Ackermann RT, O'Brien MJ. Evidence and Challenges for Translation and Population Impact of the Diabetes Prevention Program. *Curr Diab Rep* 2020;20:1–10.
5 Gillett M, Chilcott J, Goyder L, *et al*. Prevention of type 2 diabetes: risk identification and interventions for individuals at high risk economic review and modelling. 2011.
6 National Institute for Health and Care Excellence. Type 2 diabetes: prevention in people at high risk. Public health guideline [PH38]. 2012.
7 Roberts S, Craig D, Adler A, *et al*. Economic evaluation of type 2 diabetes prevention programmes: Markov model of low- and high-intensity lifestyle programmes and metformin in participants with different categories of intermediate hyperglycaemia. *BMC Med* 2018;16:16.
8 Lemp JM, Bommer C, Xie M, *et al*. Quasi-experimental evaluation of a nationwide diabetes prevention programme. *Nature New Biol* 2023;624:138–44.
9 Dunkley AJ, Bodicoat DH, Greaves CJ, *et al*. Diabetes prevention in the real world: effectiveness of pragmatic lifestyle interventions for the prevention of type 2 diabetes and of the impact of adherence to guideline recommendations: a systematic review and meta-analysis. *Diabetes Care* 2014;37:922–33.
10 Penn L, Rodrigues A, Haste A, *et al*. NHS Diabetes Prevention Programme in England: formative evaluation of the programme in early phase implementation. *BMJ Open* 2018;8:e019467.
11 Schwarz PEH, Schuppenies A, Gruhl U, *et al*. Prävention des typ-2-diabetes in Deutschland. Von der idee über die evidenz zur implementierung. *Med Klin* 2006;101:730–6.
12 Neumann A, Schwarz P, Lindholm L. Estimating the cost-effectiveness of lifestyle intervention programmes to prevent diabetes based on an example from Germany: Markov modelling. *Cost Eff Resour Alloc* 2011;9:17.
13 Palmer AJ, Roze S, Valentine WJ, *et al*. Intensive lifestyle changes or metformin in patients with impaired glucose tolerance: modeling the long-term health economic implications of the diabetes prevention program in Australia, France, Germany, Switzerland, and the United Kingdom. *Clin Ther* 2004;26:304–21.
14 Brennan A, Ara R, Sterz R, *et al*. Assessment of clinical and economic benefits of weight management with sibutramine in general practice in Germany. *Eur J Health Econ* 2006;7:276–84.
15 Ara R, Brennan A. The cost-effectiveness of sibutramine in non-diabetic obese patients: evidence from four Western countries. *Obes Rev* 2007;8:363–71.
16 Herman WH, Hoerger TJ, Brandle M, *et al*. The cost-effectiveness of lifestyle modification or metformin in preventing type 2 diabetes in adults with impaired glucose tolerance. *Ann Intern Med* 2005;142:323–32.
17 Hoerger TJ, Segel JE, Zhang P, *et al*. Validation of the CDC-RTI diabetes cost-effectiveness model. 2014.
18 Zhuo X, Zhang P, Gregg EW, *et al*. A Nationwide Community-Based Lifestyle Program Could Delay Or Prevent Type 2 Diabetes Cases And Save $5.7 Billion In 25 Years. *Health Aff (Millwood)* 2012;31:50–60.
19 Brownson CA, Hoerger TJ, Fisher EB, *et al*. Cost-effectiveness of diabetes self-management programs in community primary care settings. *Diabetes Educ* 2009;35:761–9.
20 Hoerger TJ, Zhang P, Segel JE, *et al*. Improvements in risk factor control among persons with diabetes in the United States: evidence and implications for remaining life expectancy. *Diabetes Res Clin Pract* 2009;86:225–32.
21 Weinstein MC, O'Brien B, Hornberger J, *et al*. Principles of good practice for decision analytic modeling in health-care evaluation: report of the ISPOR Task Force on Good Research Practices--Modeling Studies. *Value Health* 2003;6:9–17.
22 Ashra NB, Spong R, Carter P, *et al*. A systematic review and meta- analysis assessing the effectiveness of pragmatic lifestyle interventions for the prevention of type 2 diabetes mellitus in routine practice about public health England. England Public Health; 2015.1–172.
23 Laxy M, Backer J, Kähm K, *et al*. Diabetes, related complications, and quality of life: a german reference value set based on a population-based survey. 2020.
24 Kähm K, Stark R, Laxy M, *et al*. Assessment of excess medical costs for persons with type 2 diabetes according to age groups: an analysis of German health insurance claims data. *Diabet Med* 2020;37:1752–8.
25 Holle R, Happich M, Löwel H, *et al*. KORA - A Research Platform for Population Based Health Research. *Gesundheitswesen* 2005;67:19–25.
26 Hoerger TJ, Alva M, Neuwahl S, *et al*. A markov model of disease progression and cost-effectiveness for type 2 diabetes. Technical report. 2017.
27 Icks A, Haastert B, Arend W, *et al*. Patient time costs due to self-management in diabetes may be as high as direct medical costs: results from the population-based KORA survey FF4 in Germany. *Diabet Med* 2020;37:895–7.
28 Ulrich S, Holle R, Wacker M, *et al*. Cost burden of type 2 diabetes in Germany: results from the population-based KORA studies. *BMJ Open* 2016;6:e012527.
29 National Institute of Clinical Excellence. Technology appraisal guidance. 2022. Available: https://www.nice.org.uk/about/what-we-do/our-programmes/nice-guidance/nice-technology-appraisal-guidance
30 Skoupá J, Annemans L, Hájek P. Health Economic Data Requirements and Availability in the European Union: Results of a Survey Among 10 European Countries. *Val Health Reg Issues* 2014;4:53–7.
31 Gandjour A. Willingness to pay for new medicines: a step towards narrowing the gap between NICE and IQWiG. *BMC Health Serv Res* 2020;20:343.
32 Groos S, Dipl-PJ K, Macare C, *et al*. *Qualitätssicherungsbericht 2015: Disease-Management-Programme in Westfalen-Lippe*. Cologne, 2017.
33 Colagiuri S, Walker AE. Using An Economic Model Of Diabetes To Evaluate Prevention And Care Strategies In Australia. *Health Aff (Millwood)* 2008;27:256–68.
34 Li R, Qu S, Zhang P, *et al*. Economic Evaluation of Combined Diet and Physical Activity Promotion Programs to Prevent Type 2 Diabetes Among Persons at Increased Risk: A Systematic Review for the Community Preventive Services Task Force. *Ann Intern Med* 2015;163:452–60.
35 Neumann A, Lindholm L, Norberg M, *et al*. The cost-effectiveness of interventions targeting lifestyle change for the prevention of diabetes in a Swedish primary care and community based prevention program. *Eur J Health Econ* 2017;18:905–19.
36 Laxy M, Zhang P, Ng BP, *et al*. Implementing Lifestyle Change Interventions to Prevent Type 2 Diabetes in US Medicaid Programs: Cost Effectiveness, and Cost, Health, and Health Equity Impact. *Appl Health Econ Health Policy* 2020;18:713–26.
37 International Diabetes Federation. *IDF Diabetes Atlas*, 10th Edition. Brussels, Belgium: IDF Executive Office, 2021.
38 World Health Organization. Protecting children from the harmful impact of food marketing: policy brief. 2022.
39 World Health Ogranisation. Policy brief: taxing sugar-sweetened beverages. Copenhagen, 2022.
40 Hill-Briggs F, Adler NE, Berkowitz SA, *et al*. Social Determinants of Health and Diabetes: A Scientific Review. *Diabetes Care* 2021;44:258–79.
41 Emmert-Fees KMF, Amies-Cull B, Wawro N, *et al*. Projected health and economic impacts of sugar-sweetened beverage taxation

in Germany: A cross-validation modelling study. *PLoS Med* 2023;20:e1004311.
42 Icks A, Rathmann W, Haastert B, *et al*. Clinical and cost-effectiveness of primary prevention of Type 2 diabetes in a "real world" routine healthcare setting: model based on the KORA Survey 2000. *Diabet Med* 2007;24:473–80.
43 Herman WH, Edelstein SL, Ratner RE, *et al*. Effectiveness and cost-effectiveness of diabetes prevention among adherent participants. *Am J Manag Care* 2013;19:194–202.
44 Herman WH. The cost-effectiveness of diabetes prevention: results from the Diabetes Prevention Program and the Diabetes Prevention Program Outcomes Study. *Clin Diabetes Endocrinol* 2015;1:9.