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Projected number of people with diagnosed Type 2 diabetes in Germany in 2040*

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Abstract

Aims To project the number of people with Type 2 diabetes in Germany between 2015 and 2040.

Methods Based on data from 65 million insurees of the German statutory health insurance, we projected the age-specific prevalence of diabetes using mathematical relations between prevalence, incidence rate and mortality. We compared several scenarios regarding temporal trends in the incidence and mortality rate. The projected age-specific prevalence was applied to the projected age structure of the German population between 2015 and 2040 to calculate the number of people with Type 2 diabetes.

Results Application of current age-specific prevalence estimates to the projected age structure in 2040, although ignoring temporal trends in incidence and mortality, yielded an increase in the number of Type 2 diabetes cases from 6.9 million in 2015 to 8.3 million (+21%) in 2040. More realistic scenarios that account for decreasing mortality rates and different trends in the incidence rates project between 10.7 million (+54%) and 12.3 million (+77%) Type 2 diabetes cases in 2040.

Conclusions For the first time, we projected the number of future Type 2 diabetes cases for the whole adult population in Germany. The results indicate a relative increase in the number of Type 2 diabetes cases of between 54% and 77% from 2015 to 2040. Temporal trends in the incidence rate are the main drivers of this increase. Simply applying current age-specific prevalence to the future age structure probably underestimates the future number of Type 2 diabetes cases.

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Introduction

The prevalence of diabetes is increasing worldwide [1]. Current estimates for diagnosed diabetes in Germany are between 7.2%, based on health examination surveys for the population aged 18–79 years, and 9.9%, based on statutory health insurance data for all age groups [2]. The largest proportion is attributable to Type 2 diabetes mellitus, with an estimated prevalence of 7.4% among men and 7.0% among women aged 40 years or older [3]. Because of increased mortality and morbidity, Type 2 diabetes imposes a substantial disease burden on the population [4]. It is estimated that 140 000 deaths per year are due to increased mortality in persons with Type 2 diabetes in Germany [5]. Moreover, age-adjusted direct healthcare costs are 1.7 times higher than those for persons without Type 2 diabetes [6]. Owing to demographic changes, the number of people with Type 2 diabetes is likely to increase [7]. Quantifying this increase is important to estimate the future disease burden due to Type 2 diabetes.

Previous projections of the number of Type 2 diabetes cases in Germany estimated a strong increase, but were limited to certain age ranges and/or data from selected health insurances of the German statutory health insurance [8–10]. Relying on data from one health insurance is problematic, since it is known that insurees differ across health insurances, e.g. with regard to demographics and individual health risks [11]. These differences impair the generalizability of the projections to the German population. In addition, many previous studies only considered the changing age structure in the general population to project future case numbers,

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What's new?

- Previous projections of the number of people with Type 2 diabetes in Germany considered only certain age ranges and/or ignored temporal trends in the incidence and mortality rates.
- This study estimated a relative increase in Type 2 diabetes cases in Germany of between 54% and 77%, resulting in 10.7 million to 12.3 million cases in 2040.
- Ignoring trends in the incidence and mortality rates severely underestimated the number of Type 2 diabetes cases.
- There will be increased demand for diabetes healthcare resources and education of specialists in diabetes care, which has likely been underestimated by previous projections.

thereby neglecting the important role of the incidence rate of Type 2 diabetes and the mortality rate of persons with Type 2 diabetes. Valid projections need to incorporate temporal trends in incidence and mortality rates, since these are likely to influence the number of future cases.

Thus, in this study, we project sex-stratified case numbers of Type 2 diabetes for Germany for the years between 2015 and 2040, using data from all persons in the statutory health insurance, and currently available estimates for the Type 2 diabetes incidence and mortality of persons with Type 2 diabetes.

Methods

For this study, we used published data on Type 2 diabetes prevalence, incidence and mortality that are considered to be representative for Germany [3,12,13]. We used an illness–death model (Fig. S1) to project the future age-specific prevalence between 2015 and 2040. Population projections from the German Federal Statistical Office [12] were used to calculate the number of people with Type 2 diabetes.

Calculation of age-specific prevalence of Type 2 diabetes

To incorporate temporal trends in incidence and mortality rates, we used a partial differential equation, which describes the relation between prevalence, incidence rate and mortality rate as a function of age and calendar time [14]. Because the mortality rate of people with Type 2 diabetes is higher compared with people without Type 2 diabetes, we incorporated the mortality rate ratio into the equation. The mortality rate ratio was defined as the ratio of the mortality rates of people with vs without Type 2 diabetes. Using input values for the mortality rate of the general population, prevalence, incidence rate and mortality rate ratio, the partial differential equation can be used to calculate the prevalence in each year between 2015 and 2040 for each age group. Temporal changes in the incidence and mortality rates from one year to the next year can be incorporated into the model (see online Supporting Information).

Starting values for the age-specific Type 2 diabetes prevalence and incidence rate for 2010 were based on data from 65 million insurees of the statutory health insurance and included all health insurances in the German statutory health insurance as well as all age groups [3]. The mortality rate of the general population between 2015 and 2040 was obtained from population projections of the German Federal Statistical Office [12]. Input values for the age-specific mortality rate ratio were based on estimates from the mortality follow-up of the German Health Interview and Examination Survey participants [13].

Based on the age-specific prevalence in 2010, we projected five different scenarios for the age-specific prevalence between 2015 and 2040. In scenario 1, we assume that the age-specific prevalence remains constant between 2015 and 2040. In scenarios 2–5, we considered different temporal trends of the incidence rate and mortality rate ratio. Because data on long-term trends in the incidence rate and mortality rate ratio are limited in Germany [2], we used hypothetical temporal trends. Scenario 2 assumes a constant incidence rate and mortality rate ratio. In contrast to scenario 1 (constant age-specific prevalence), scenario 2 accounts for the decreasing mortality rate in the general population. Owing to advancements in medical care, it is likely that the mortality rate among persons with Type 2 diabetes will decrease faster than the mortality rate among persons without Type 2 diabetes [15,16]. Hence, scenarios 3–5 assume that the mortality rate ratio decreases by 2% per year, as observed in Denmark [15]. The three scenarios with decreasing mortality rate ratio differ with regard to the temporal trends of the incidence rate. Scenario 3 assumes a constant incidence rate, and scenarios 4 and 5 assume an increase and decrease by 0.5% per year, respectively.

Table 1 Variants of the population projections of the German Federal Statistical Office for the years 2015 to 2060 [12]

Variant	Birth rate (children per woman)	Life expectancy at birth in 2060 (years)	Long-term net migration
1 (B1L1M1)	1.4	Boys: 84.8 Girls: 88.8	100 000
2 (B1L1M2)	1.4	Boys: 84.8 Girls: 88.8	200 000
3 (B1L2M1)	1.4	Boys: 86.7 Girls: 90.4	100 000
4 (B1L2M2)	1.4	Boys: 86.7 Girls: 90.4	200 000

B, birth rate; L, life expectancy at birth; M, long-term net migration.

Calculation of case numbers of Type 2 diabetes

Case numbers of Type 2 diabetes in Germany between 2015 and 2040 were derived for 1-year age groups by multiplying the projected prevalence from the partial differential equation by the projected population size [12] of that age group. We considered the population older than 18 years, because the prevalence at younger ages is negligible [3].

The population projections of the Federal Statistical Office consider different variants for future life expectancy at birth, birth rate and migration. We considered variants 1–4 of the population projections (Table 1).

Sensitivity analysis

In sensitivity analyses, we assessed two further scenarios for the incidence rate. First, we assumed a decrease in the incidence rate of 5% per year, which was observed in Germany between 2012 and 2014 [17]. Second, we assumed an increase in the incidence rate by 3% per year, as observed in Denmark between 1995 and 2010 [18].

Besides uncertainty due to future trends in the model parameters, uncertainty could also arise due to sampling error of the input values. Therefore, we performed a Monte Carlo simulation for scenario 2, accounting for the sampling error of all input values (see online Supporting Information).

All analyses were performed using the free software R, v. 3.2.4 (The R Foundation for Statistical Computing).

We used published data on an aggregated level. No individual data on humans or animals were involved in this study. Therefore, an ethics committee approval was not necessary.

Results

Projected prevalence

Figure 1 shows the projected age-specific prevalence of Type 2 diabetes for the five scenarios in the years 2015, 2020, 2030 and 2040 under moderately increasing life expectancy (assumption L1 in Table 1). Compared with scenario 1 with constant age-specific prevalence, all scenarios project a markedly increasing prevalence, particularly in older age groups. Moreover, the peak prevalence is shifted towards older age groups. In 2040, the prevalence peaks at ~ 90 years of age, lying between 40–50% and 50–60% among women and men, respectively. The differences in the age-specific prevalence among the scenarios are also apparent in the overall prevalence (Fig. 2). The smallest increase is observed in the scenario with constant age-specific prevalence. In all other scenarios, the increase in prevalence is higher. The different variants of the Federal Statistical Office (Table 1) had almost no influence on the projected prevalence (Fig. S2).

Projected number of Type 2 diabetes cases

Figure 3 shows the projected number of Type 2 diabetes cases in Germany in 2015 and 2040 for all incidence and mortality rate ratio scenarios for variant 2 of the population projections. Results only differed slightly between the variants of the population projections (Fig. S2 and Table S1). Assuming constant age-specific prevalence, the number of Type 2 diabetes cases is projected to increase by 1.4 million, resulting in a total of 8.3 million cases in 2040 (+21%). Accounting for increasing life expectancy in the general population while assuming a constant incidence rate and mortality rate ratio (scenario 2), cases are projected to increase by 4.1 million (+59%). If the mortality rate ratio decreases by 2% per year (scenario 3), the number of cases is projected to increase by 4.6 million (+65%). If, in addition, the incidence rate increases by 0.5% per year (scenario 4), the number of cases is projected to increase by 5.4 million (+77%). Under a decreasing incidence rate (scenario 5), the number of cases is projected to increase by 3.8 million (+54%).

Sensitivity analyses

In sensitivity analyses, incidence trends of −5% and +3% were analysed. In these extreme scenarios, the number of Type 2 diabetes cases between 2015 and 2040 is projected to decrease by −0.9 million (-14%) and to increase by 10.5 million (+147%), respectively (Table S1).

The uncertainty due to sampling error of the input values was much lower and led to deviations between 5% and 7% (online Supporting Information).

Discussion

The results indicate a substantial increase in the number of persons with Type 2 diabetes in Germany between 2015 and 2040. Applying the current prevalence to the projected age structure of the population in 2040 led to an estimated increase of 1.4 million (+21%) cases from 2015. Taking into account different scenarios about trends in incidence and mortality rates yields increases between 3.8 million (+54%) and 5.4 million (+77%) cases. Compared with the effect of changes in the mortality rate ratio, variation in the incidence rates had a stronger impact on the number of future cases. A relatively low decrease in the incidence of −0.5% per year reduces the increase in future cases by 11 percentage points, compared with the scenario of constant incidence. However, a decrease in the mortality rate ratio of 2% each year leads to only a 6 percentage points greater increase in the number of cases, compared with the scenario of constant mortality rate ratio.

In the scenario with constant age-specific prevalence, the age-specific prevalence from 2015 is applied without any temporal trend to the future projected age distribution of the

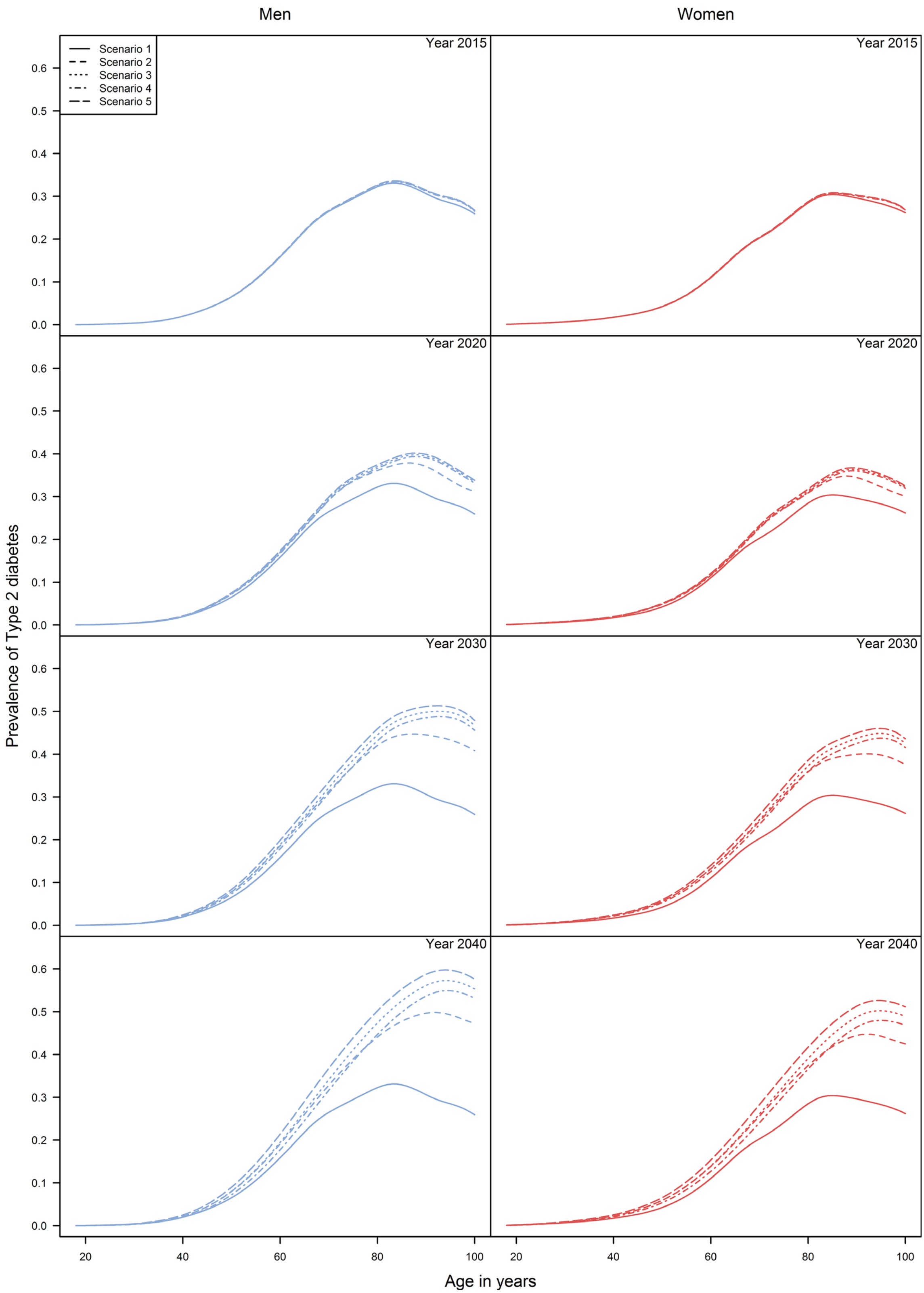

FIGURE 1 Projected age-specific prevalence of Type 2 diabetes in Germany among women (red) and men (blue) in 2015, 2020, 2030 and 2040. Projections are for variant 2 of the population projections of the German Federal Statistical Office [12]. Scenario 1, constant age-specific prevalence; scenario 2, constant Type 2 diabetes incidence rate (IR), constant mortality rate ratio (MRR); scenario 3, constant IR, MRR −2% per year; scenario 4, IR −0.5% per year, MRR −2% per year; scenario 5: IR +0.5% per year, MRR −2% per year.

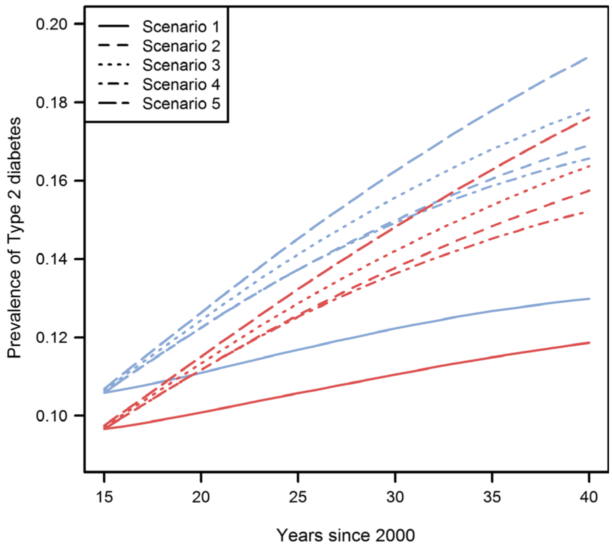

FIGURE 2 Projected overall prevalence of Type 2 diabetes in Germany among women (red) and men (blue) for variant 2 of the population projections of the German Federal Statistical Office [12] between 2015 and 2040. Variant 2 of the population projections assumes constant birth rates, moderate increases in life expectancy and a net migration of 200 000 people (Table 1). Scenario 1, constant age-specific prevalence; scenario 2, constant Type 2 diabetes incidence rate (IR), constant mortality rate ratio (MRR); scenario 3, constant IR, MRR −2% per year; scenario 4, IR −0.5% per year, MRR −2% per year; scenario 5, IR +0.5% per year, MRR −2% per year.

population. Thus, the impact of changing incidence and mortality rates on the prevalence was completely ignored. Hence, the scenarios based on assumptions about changing incidence rates and mortality rate ratios are more plausible. In the Supporting Information, we use empirical data to show that the mathematical model yields more valid results than assuming constant prevalence. Given that the scenarios incorporating assumptions about the rates in the illness–death model are more plausible, the scenario with constant age-specific prevalence probably underestimates the projected number of Type 2 diabetes cases.

We can only speculate which scenario from the mathematical model is most likely. In general, scenarios with decreasing mortality rate ratios seem more likely, assuming that treatment of diabetes will further improve. In addition, temporal trends in different countries suggest decreasing trends in the mortality rate ratio [15,19,20]. With regard to trends in the incidence rate, the evidence is equivocal. Although the prevalence of obesity has increased in Germany [21], trends from the German Diabetes Risk Score over 12 years indicate a decreasing Type 2 diabetes risk [22]. Goffrier *et al.* [17] also reported decreasing Type 2 diabetes incidence rates. Hence, scenarios with decreasing incidence rates might be more likely.

In sensitivity analyses, we assumed strong temporal trends in incidence, which, in turn, led to considerably large changes in the number of future cases (−14% and +147%). Uncertainty due to sampling error in the input values seems to be of limited importance because it only causes deviations between 5% and 7% (online Supporting Information).

Because data from Germany are scarce, evidence from other countries on long-term incidence trends could potentially inform a plausible scenario. However, within Europe, trends in incidence rates are heterogeneous. In Denmark, yearly increases between 3.8% [18] and 5.0% [23] for men and women have been found, whereas the rate is decreasing among Finnish women and is stable among Finnish men [24]. From Scotland, it has been reported that the incidence rate is increasing among young men and is stable among young women, whereas it is decreasing among the elderly population [25]. In Sweden, the incidence decreases among men and women [26]. This heterogeneity emphasizes that country-specific and long-term evaluation of the incidence rate is necessary to gain more certainty about the future number of Type 2 diabetes cases.

Another potential source of long-term trends in incidence and mortality rates could be the Global Burden of Disease Study, which provides country-specific trends between 1990 and 2016 [27]. However, the methods of the Global Burden of Disease Study comprise temporal and spatial extrapolation where data are scarce [28]. Because long-term trends in age-specific incidence rates are heterogeneous between European countries, using regionally extrapolated information for a specific country could be misleading. In a recent review, Heidemann and Scheidt-Nave [2] concluded that consistent long-term trends in the incidence rate are not available in Germany. Thus, the trends available from the Global Burden of Disease Study are based on extrapolated data to a considerable extent. Furthermore, the diabetes-related mortality in the Global Burden of Disease Study is based on causes of deaths from death certificates. This information cannot be used to calculate the mortality rate of people with Type 2 diabetes because the use of death certificates underestimates the true number of deaths due to Type 2 diabetes [5].

Comparison with previous studies

Previous projections for Germany also suggested a strong increase in the number of Type 2 diabetes cases. Brinks *et al.* [8] estimated that the number of cases will increase by 0.95 million between 2010 and 2040 in the population aged 55–74 years. Across all age groups, Braun *et al.* [9] estimated an increase between 1.22 and 1.45 million cases between 2015 and 2040. However, Braun *et al.* assumed constant age-specific prevalence, which yielded results in line with those of our constant prevalence scenario. Wilke *et al.* [10] also used this method and projected an increase of 0.68 million between 2008 and 2020. A marked increase in the number of Type 2 diabetes cases is projected in other countries as well, e.g. the USA [29] and Australia [30]. Worldwide, Wild *et al.* [31] predict 195 million additional cases between 2000

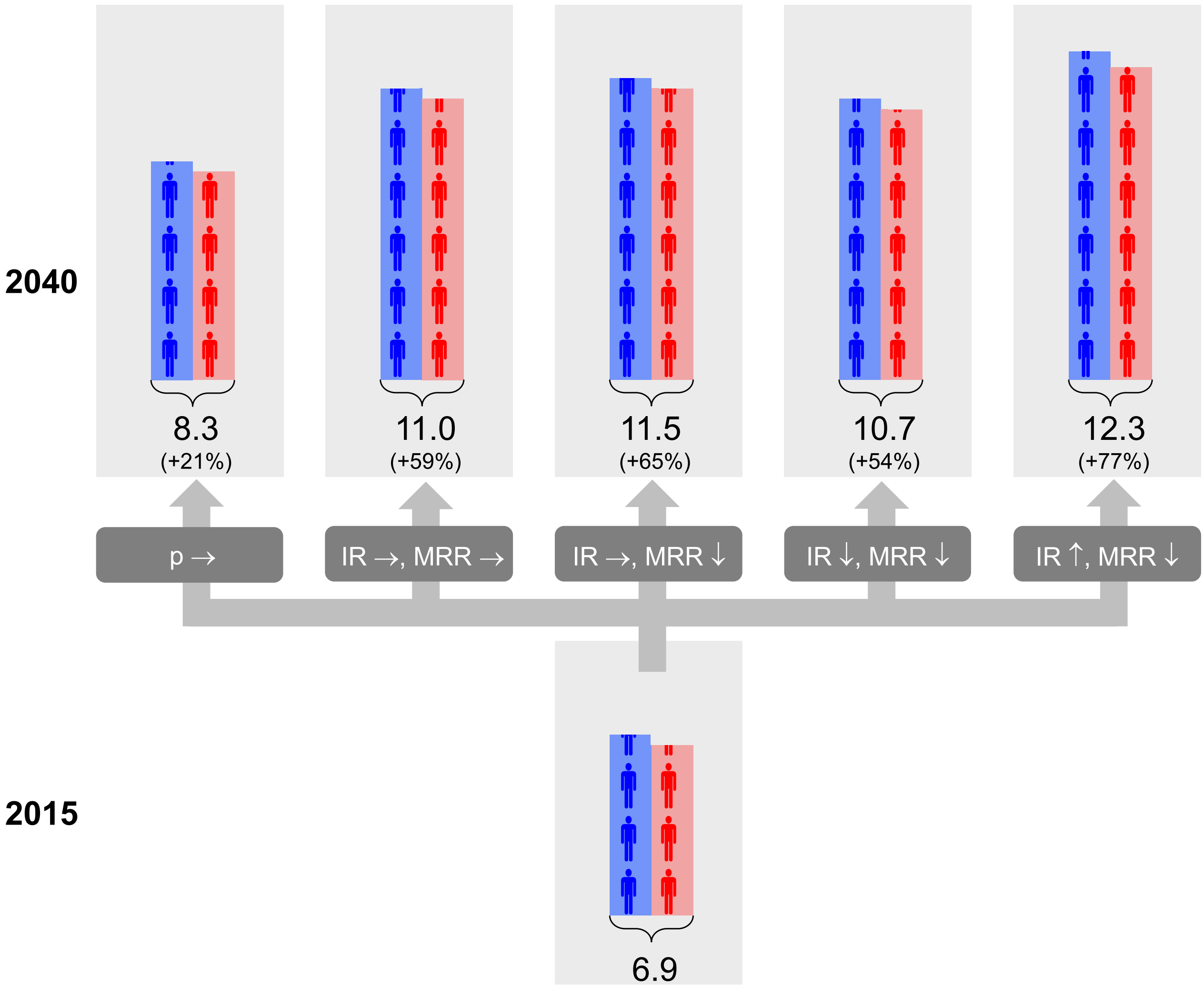

FIGURE 3 Projected number of women (red) and men (blue) with Type 2 diabetes in Germany in 2015 and 2040. Numbers are in millions with the relative change in %. One pictographic person represents 1 million individuals. The five bar charts for 2040 represent five different scenarios with regard to temporal trends in prevalence (p), the incidence rate (IR) and the mortality rate ratio (MRR). →, constant age-specific p/IR/MRR; MRR ↓, decrease in MRR by 2% per year between 2015 and 2040; IR ↑/↓, increase/decrease in IR by 0.5% per year between 2015 and 2040.

and 2030. The International Diabetes Federation projects 227 million and 11.8 million additional cases world- and Europe-wide, respectively, between 2015 and 2040 [32]. All these studies neglect relevant age groups and/or the role of the incidence and mortality rates.

Historical trends in Type 2 diabetes prevalence are also in line with our findings. For instance, an increase in age-standardized prevalence of ~ 50% in Western Europe between 1980 and 2008 has been reported [1]. Over a similar time frame (2015 to 2040), we projected an analogous increase in prevalence in scenario 2 and 4 (Fig. 2).

Implications for public health and clinical practice

The strong projected increases in the number of people with Type 2 diabetes in Germany underline that there will be an intensified need for diabetes healthcare facilities and education of specialists as well as a growing economic burden as Type 2 diabetes is associated with a substantial increase in healthcare costs [6]. Furthermore, our results suggest that clinical practice will face a rising number of elderly people with Type 2 diabetes, because the projected prevalence particularly increased in the age groups beyond 80 years. Because Germany has the largest population in Western Europe, these results could indicate Europe-wide developments in future healthcare needs related to Type 2 diabetes.

The finding that the incidence rate was the main driver of future case numbers highlights the importance of population-based prevention of Type 2 diabetes. We showed that even small decreases in the incidence rate can prevent a large amount of cases. This is a general finding that should be applicable to other countries than Germany as well. The finding that ignoring temporal trends in incidence and mortality probably underestimates the future need for healthcare resources might be very important for all countries that lack valid projections and are facing increases in Type 2 diabetes prevalence. Our methodological approach is generally applicable in all countries. Analysis code for such projections is available in [14].

Strengths and limitations

Our study has some strengths and weaknesses. One weakness is a slight difference in our projected prevalence from the observed prevalence in 2015 (Fig. S3). These deviations may be because we assumed the same trends in the incidence rate and mortality rate ratio, irrespective of age and sex, although these trends probably differ by age and sex, e.g. because of different trends in obesity. Thus, this assumption probably oversimplifies the trends. Further reasons for these differences might be that Goffrier *et al.* [17] used only claims data from outpatient care, whereas Tamayo *et al.* [3] also used data from inpatient care. Furthermore, slightly different diagnostic criteria in the data were used to define Type 2 diabetes. Although the deviations were small in 2015, we cannot exclude that observed and estimated prevalence would deviate in greater proportions beyond 2015.

As a second limitation, we only included information on diagnosed Type 2 diabetes. Thus, the substantial, albeit decreasing [32,33], proportion of the population with undiagnosed Type 2 diabetes was not taken into account in our projections. Hence, we probably underestimated the true prevalence of diabetes. Furthermore, our analyses assumed that the criteria to identify Type 2 diabetes remain the same. However, the definition of a disease usually is subject to changes over time (e.g. changes in thresholds of blood glucose that define Type 2 diabetes). Moreover, we did not account for potentially different prevalence among persons migrating to Germany in the future. However, an example with respect to another age-related chronic disease (dementia) showed that the influence of migration is small because of the relatively few migrants compared with the size of the resident population [14]. Compared with the variability between the different projection scenarios, the impact of undiagnosed Type 2 diabetes and migration appears to be of limited importance.

One strength of our study is the fact that it was based on diagnostic data from 65 million persons. These data enabled projections for the whole German population in the statutory health insurance between the ages of 18 and 100 years. Moreover, the main advantage compared with other projections is the use of mathematical relations between prevalence, incidence rates and mortality rates. In this way, future trends in incidence and mortality can be considered in parallel, and crude extrapolation of current prevalence to future age distributions is no longer necessary. Thus, our method allows us to compare multiple scenarios, and can inform clinical practice and health policy about the impact of changes in the incidence rate, e.g. through prevention. It has been shown that our model is mathematically equivalent to a Markov model [34].

Conclusion

For the first time, we projected the future number of Type 2 diabetes cases for the total adult population in Germany. It turned out that temporal trends in the incidence are the main drivers of the number of future cases. Uncertainty about future trends was treated by assuming different scenarios. The scenarios projected between 10.7 million (+54%) and 12.3 million (+77%) Type 2 diabetes cases in Germany in 2040. All scenarios suggest a considerable increase in the number of people with Type 2 diabetes between 2015 and 2040. Applying current age-specific prevalence estimates to projected future age structures probably underestimates this increase.

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Competing interests

None declared.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Figure S1. Illness–death model.
Figure S2. Projected overall prevalence of Type 2 diabetes in Germany among women and men for variant 1, 2, 3 and 4 of the population projections of the German Federal Statistical Office between 2015 and 2040.
Figure S3. Comparison of the observed Type 2 diabetes prevalence in Germany in 2015 with the projected Type 2 diabetes prevalence from the partial differential equation and the observed prevalence in 2010.
Figure S4. Projected number of Type 2 diabetes cases in Germany among women.
Figure S5. Projected number of Type 2 diabetes cases in Germany among men.

Table S1. Absolute and relative change in the number of Type 2 diabetes cases in Germany between 2015 and 2040 for different scenarios and variants of the population projection.
Table S2. Distribution of the projected number of Type 2 diabetes cases in Germany in 2040 in 1000 from Monte Carlo simulation with 5000 replications assuming constant Type 2 diabetes incidence rate and constant mortality rate ratio.