Health Care Costs Associated With Incident Complications in Patients With Type 2 Diabetes in Germany

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OBJECTIVE

The aim of this study is to provide reliable regression-based estimates of costs associated with different type 2 diabetes complications.

RESEARCH DESIGN AND METHODS

We used nationwide statutory health insurance (SHI) data from 316,220 patients with type 2 diabetes. Costs for inpatient and outpatient care, pharmaceuticals, rehabilitation, and nonmedical aids and appliances were assessed in the years 2013–2015. Quarterly observations are available for each year. We estimated costs (in 2015 euro) for complications using a generalized estimating equations model with a normal distribution adjusted for age, sex, occurrence of different complications, and history of complications at baseline, 2012. Two- and threefold interactions were included in an extended model.

RESULTS

The base case model estimated total costs in the quarter of event for the example of a 60- to 69-year-old man as follows: diabetic foot €1,293, amputation €14,284, retinopathy €671, blindness €2,933, nephropathy €3,353, end-stage renal disease (ESRD) €22,691, nonfatal stroke €9,769, fatal stroke €11,176, nonfatal myocardial infarction (MI)/cardiac arrest (CA) €8,035, fatal MI/CA €8,700, nonfatal ischemic heart disease (IHD) €6,548, fatal IHD €20,942, chronic heart failure €3,912, and angina pectoris €2,695. In the subsequent quarters, costs ranged from €681 for retinopathy to €6,130 for ESRD.

CONCLUSIONS

Type 2 diabetes complications have a significant impact on total health care costs in the SHI system, not only in the quarter of event but also in subsequent years. Men and women from different age-groups differ in their costs for complications. Our comprehensive estimates may support the parametrization of diabetes models and help clinicians and policy makers to quantify the economic burden of diabetes complications in the context of new prevention and treatment programs.

In Germany, the prevalence of type 2 diabetes was estimated at ~7% in 2011, which is slightly above the global average (1,2). Type 2 is the most common form of diabetes, accounting for >90% of all diabetes cases, and is largely the result of lifestyle and behavioral risk factors. The shift in risk factors as well as demographics is contributing to the increasing prevalence worldwide, especially among younger age-groups (3). This increased prevalence adds to the growing social and economic burden of diabetes, which is further driven by the occurrence of multiple heterogeneous complications (4).

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As new diabetes treatments and prevention programs are introduced to address these issues, economic evaluations are becoming more important. Tools such as systematic disease models can assist decision makers in assessing the impact on clinical outcomes and economic performance. The two widely used noncommercial type 2 diabetes models that have a substantive overlap include the Centers for Disease Control and Prevention/RTI International (CDC/RTI) model and the UK Prospective Diabetes Study (UKPDS) Outcomes Model (5,6). Both models follow patients over a lifetime horizon and simulate the development of various complications, including microvascular complications (nephropathy, diabetic foot, and retinopathy) as well as macrovascular complications. These models have, for example, been used to estimate the cost-effectiveness of an intensive glycemic control regimen, a cholesterol-reducing regimen, or other intervention programs (7,8). So far, there is no literature on a comparable German model for type 2 diabetes. Although the risk engines are probably transferable to Caucasian populations, costs mostly remain country specific. Reliable estimates are therefore needed for the use of diabetes models in the German context. To date, there are only a few related studies focusing on the health care costs of diabetes complications in Germany. However, none of these studies fulfills all the requirements necessary for a complete implementation and parametrization of such a diabetes model. Specifically, they do not distinguish between type 1 and type 2 diabetes, do not account for the temporal distribution of costs, exclude deaths, use a restrictive sample (e.g., from the state Hesse), or focus on just one single complication (9–11). With regard to the data source to be used, health claims data are the most suitable source because of the large sample size, wide coverage, and detailed cost data covering several years.

This study therefore uses nationwide health insurance data from Germany to comprehensively estimate the short- and medium-term costs of typical type 2 diabetes–related complications within a regression approach. These estimates can be used for the parametrization of diabetes models such as UKPDS and CDC/RTI and are helpful for clinicians and decision makers in quantifying the economic burden of diabetes complications.

RESEARCH DESIGN AND METHODS

Research Setting

In Germany, every citizen is required to have health insurance (either private or statutory). Currently, there are >100 statutory health insurance (SHI) funds, which are mainly historically evolved and cover ~90% of the population.

Each person is assigned a unique pseudonymous identification number, which allows every insurance fund to capture information from the same person until death, end of insurance, or even with interruptions in the insurance history. In this retrospective cohort study, we use claims data from the Techniker Krankenkasse (TK), which is the largest nationwide SHI provider in Germany, covering ~9.8 million insured people in the first half of 2017 throughout Germany.

Health claims data (especially outpatient service data) are by German social laws only available for the last 4 years. The data extraction was performed at the end of 2016; therefore, the baseline year was 2012. The development of complications and costs was then assessed during the follow-up period in 2013–2015. All analyses were performed at the WINEG institute (Scientific Institute of TK for Benefit and Efficiency in Health Care), who approved the intended use of the data. According to official guidelines, the consultation of an ethics committee is not required because of the retrospective design of the study and the on-site evaluation of data at the WINEG institute (12).

Selection of Study Population: Inclusion and Exclusion Criteria

The definition of type 2 diabetes follows a recent publication on the incidence and prevalence of diabetes in Germany (13). In this study, Tamayo et al. (13) propose a way of distinguishing between different groups of patients with diabetes based on outpatient and inpatient ICD-10 diagnoses E10–E14, namely type 1, type 2, unclear type 1 or 2, unspecified, or other diabetes. For our analysis, we concentrated on the group of patients with clear type 2 diabetes but also considered potential type 2 diabetes in the group with an unclear or unspecified diabetes diagnosis. Therefore, we linked the inclusion criteria to the prescription of oral antidiabetes medications and participation in a disease-management program (DMP) for type 2 diabetes. Regarding the first point, for example, the most commonly prescribed antidiabetes agent metformin is not licensed for individuals without diabetes in Germany. On the second point, it should be noted that >60% of the population with diabetes participates in a DMP for type 2 diabetes (14,15). A more detailed technical definition can be found in Supplementary Table 1. Before beginning the data selection, we also compared the diabetes prevalence calculated based on the TK population (standardized to the German population in 2011) with other literature. Exclusion criteria included age <18 years, certain diseases such as gestational diabetes mellitus (ICD-10 O24), pancreoprivic diabetes (E13), and pancreatic cancer, and participation in a DMP for type 1 diabetes. Furthermore, we excluded patients with an incomplete insurance history until death in the follow-up period and patients with unknown residence or residence abroad at baseline. The flowchart for the cohort selection is shown in Fig. 1.

Identification of Diabetes-Associated Complications

This study investigates macrovascular complications, including angina pectoris, chronic heart failure (CHF), myocardial infarction (MI)/cardiac arrest (CA), stroke, and other ischemic heart diseases (IHDs), as well as microvascular complications, including retinopathy, blindness, diabetic foot, lower-extremity amputation (LEA), nephropathy, and end-stage renal disease (ESRD). These are the complications in the UKPDS and CDC/RTI diabetes model, which were identified based on corresponding medical codes that were collected from the literature and publicly accessible databases (see Supplementary Tables 2 and 3 for full details of the operationalization of complications, risk factors, and medications) (16–28). Inclusion criteria for complications required that at least one outpatient or one primary or secondary inpatient ICD diagnosis was documented in the follow-up period. Complications with only one suspected diagnosis in one quarter were not taken into account. For some complications (i.e., LEA or dialysis-dependent renal insufficiency), inpatient operation/procedure codes and outpatient service codes were also used. Moreover, acute macrovascular complications (MI/CA, stroke, and IHD) were defined as nonfatal or fatal events that were limited to hospitalizations with primary diagnosis. Fatal macrovascular

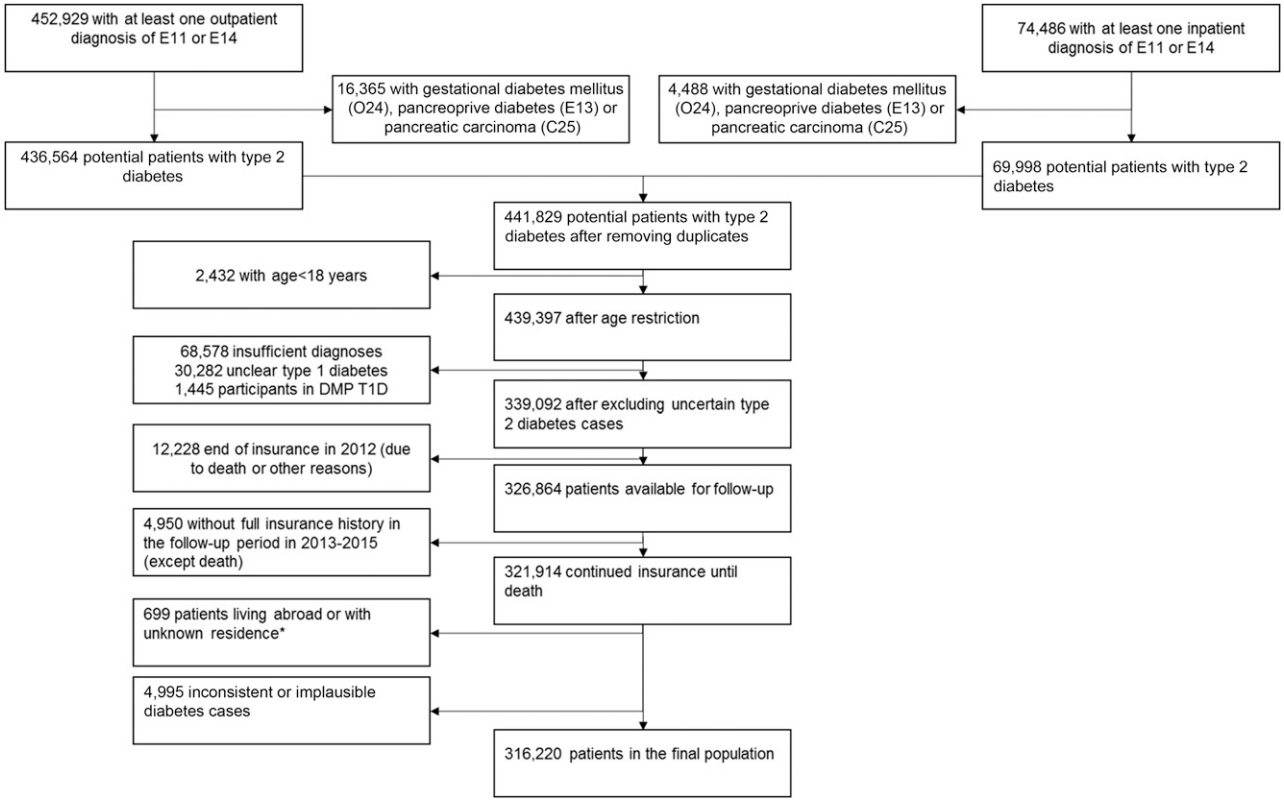

Figure 1—Selection algorithm for patients with type 2 diabetes (baseline year 2012). *At time of data selection (December 2016). Therefore, patients with temporary stay abroad are still included in the population. T1D, type 1 diabetes.

complications additionally required death as the discharge reason. The quarter of an incident complication was detected in the follow-up period by requiring a washout period of 1 year (that is the baseline year 2012) free of diagnoses of the specific complication. If a complication was present at baseline, patients were assigned as having a history of the complication.

Resources and Costs

By applying an SHI perspective, health care costs include costs for outpatient and inpatient services, medication, rehabilitation, and the provision of aids and appliances. Therefore, copayments to medical services covered by SHI are included in the data set, whereas patients' out-of-pocket payments for other services are not. All costs are expressed in 2015 euros using official inflation data from the Federal Statistical Office (29). Outpatient diagnoses are only available on a quarter level. For inpatient data, the admission and discharge dates are available. In line with an SHI perspective, we used the discharge date to determine the corresponding quarter.

Data Preprocessing and Statistical Analysis

Before the actual statistical analysis, data were subjected to quality and plausibility checks as requested by common guidelines for secondary data analysis (12). This included, for example, checking for negative or zero total hospital payments, implausible lengths of stay in hospital, or charged costs after death (see Supplementary Table 4). Additionally, cost data were plotted in a boxplot and histogram to identify possible outliers. We prepared the data in the form of 12 observation periods of 3 months per patient, representing the number of calendar quarters in the 3-year follow-up period. We allowed for deviations of the time of onset of the complication by consecutively numbering quarters without complication with zero, the quarter of event with 1, and the following quarters with 2 to up to 12. In accordance with the requirements of the implementation of costs in diabetes models, we estimated the impact of complications in at least two time periods: within the quarter in which the complication occurs and in subsequent quarters (i.e., $<$1 year after the onset of complication and $>$1 year after the onset of complication). Similar to Alva et al. (22), we assume that the later time periods are likely to reflect the ongoing impact of complications, including subsequent events of the same type. Patients who already experienced this complication at baseline are extracted in separate dummy variables, which stay the same during the follow-up period. All patients were followed up until death or end of 2015. A generalized estimating equations (GEE) model was used to account for the nonindependence of observations within each subject during the period of the study (see Supplementary Statistical Appendix for the detailed model notation). In line with literature recommendations, we can assume a near normality of the sample means, as the sample size is sufficiently large and the proportion of zero costs relatively small ($<$2%) (30). Furthermore, the GEE model with a normal distribution showed better model fit based on the mean square error and residual plot compared with a γ-based GEE model where €1 was assigned for patients with zero costs. While the normal distribution also has favorable properties

for run-time efficiency, the quantification of probabilistic uncertainty, and the interpretability of results, other data transformation methods, such as the logarithmic transformation, have several drawbacks on their own (31). To address challenges associated with extreme outliers, costs were winsorized at 99.9% (by sex) in a sensitivity analysis. Winsorization is a way to minimize the influence of outliers in the data by replacing extreme values based on percentiles. All analyses were performed using SAS Enterprise Guide version 7.1 with SAS version 9.4 (SAS Institute Inc., Cary, NC).

RESULTS

Sample Characteristics

Table 1 describes the baseline sociodemographic and clinical characteristics of the study sample, which consisted of 316,220 patients. Approximately 61% of the population was found to participate in a DMP for type 2 diabetes in 2012. Hypertension and obesity were frequently present in ~81% and 30%, respectively. Obesity and depression were thereby more frequent in women (34% vs. 28% and 26% vs. 14%), whereas alcohol and tobacco abuse and malignant cancer were more frequent in men (10% vs. 7% and 16% vs. 13%). Men also exhibited a slightly higher adapted Diabetes Complication Severity Index (aDCSI) score of 1.9 vs. 1.5 (see Supplementary Tables 5 and 6 for further details on the calculation of the aDCSI score and distribution in the population) (25).

Diabetes Prevalence

In the TK population, the standardized prevalence of clear type 2 diabetes cases (ICD E11) was calculated at 5.6% in 2012 (6.15% for men and 5.10% for women). When taking all diabetes forms into account (including unclear or unspecified type 2 diabetes but also type 1 and other types of diabetes), an overall prevalence of 8.5% and 7.0% was calculated for men and women, respectively.

Descriptive Analysis

In our population, complications occurred with the following frequencies: nephropathy (17.7% observed new cases), diabetic foot (15.5%), CHF (13.4%), retinopathy (11.3%), angina pectoris (5.5%), stroke (2.5%), MI/CA (2.0%), other IHD (2.0%), ESRD (1.2%), amputation (0.6%), and blindness (0.6%).

On the cost side, total raw mean costs increased from €4,688 in 2013 by ~5.6% to €4,949 in 2015 (see Supplementary Fig. 1*A* and *B*). Most of the costs are related to inpatient care (42%), pharmaceuticals (27%), and physician care (20%). In age-groups <60 years, costs were higher in women, whereas costs were higher in men in higher age-groups. Figure 2 shows the development of costs before, during, and after the occurrence or onset of certain complications (information on the number of patients that were included in the calculations as well as the cost factor relative to the absence of complications can be found in Supplementary Fig. 2). Costs in the quarter of event were the highest for LEA, ESRD, and all three acute events (MI/CA, stroke, and other IHD), ranging from €9,309 to €30,739 for nonfatal and fatal IHD, respectively. The distribution of costs indicates no or only a slight peak for chronically evolving complications such as retinopathy, nephropathy, or foot complications at the quarter of first diagnosis. The costs here are growing slowly or remain stagnant. This is in contrast to acute or very severe complications such as LEA, ESRD, and acute macrovascular events, where a clear high peak can be identified. There is also a difference between LEA and acute macrovascular complications, showing that the decline in costs is relatively slower for acute macrovascular complications in the subsequent periods.

Table 1—Baseline characteristics in 2012

	Overall (*n* = 316,220)	Female (*n* = 116,010)	Male (*n* = 200,210)
Participation in the DMP for type 2 diabetes (%)*	61.2	61.0	61.3
Sex (%)		36.7	63.3
Age, years, mean (min, max)	65.9 (18, 106)	66.3 (18, 101)	65.6 (18, 106)
Age-group, years, %			
<50	8.6	9.3	8.2
50–59	19.4	18.2	20.1
60–69	29.6	28.0	30.5
70–79	32.4	32.1	32.6
>80	10.0	12.4	8.5
Type of antidiabetes treatment, %			
None	37.9	42.3	35.3
Only oral	47.4	44.6	48.9
Oral + insulin	9.2	8.1	9.9
Only insulin	5.5	5.0	5.9
aDCSI score, mean (min, max)	1.747 (0, 12)	1.545 (0, 12)	1.864 (0, 12)
Risk factors (ICD codes), %			
Hypertension (I10–I15)	80.5	80.0	80.7
Alcohol/tobacco (F10, F17)	9.0	6.6	10.4
Depression (F32–F34)	18.4	26.3	13.8
Obesity (E66)	30.1	34.2	27.7
Sleeping disorder (G47, F51)	12.9	12.0	13.4
Malignant cancer (C00–C97)	14.7	13.1	15.7

max, maximum; min, minimum. *Participation for at least 1 day.

Regression Analysis

Table 2 shows the estimated coefficients obtained from the GEE model. Because the estimates are directly interpreted as costs, the intercept of €780 represents fixed costs for a female patient aged 70–79 years without any complications for a 3-month period, which corresponds to about €3,120 for a whole year. The same patient with a diabetic foot diagnosis would have additional costs of around €640 for the quarter of diagnosis and around €370 of additional costs in the following quarters. Owing to the large sample size, confidence intervals will be small. Supplementary Tables 7 and 8 report estimates and predictions of costs from the regression, including interaction effects between age, sex, and complications. Total costs were calculated separately for men, women, and age-groups to meet the basic requirements for model parametrization. In addition, results are also presented on an annualized basis. The annualized costs per complication (in 2015 euros) for the example of a 60- to 69-year-old man ranged from €2,539 for retinopathy to €34,547 for ESRD in the year of event, and from €2,469 to €24,662 for retinopathy and ESRD in the following years, respectively. Costs

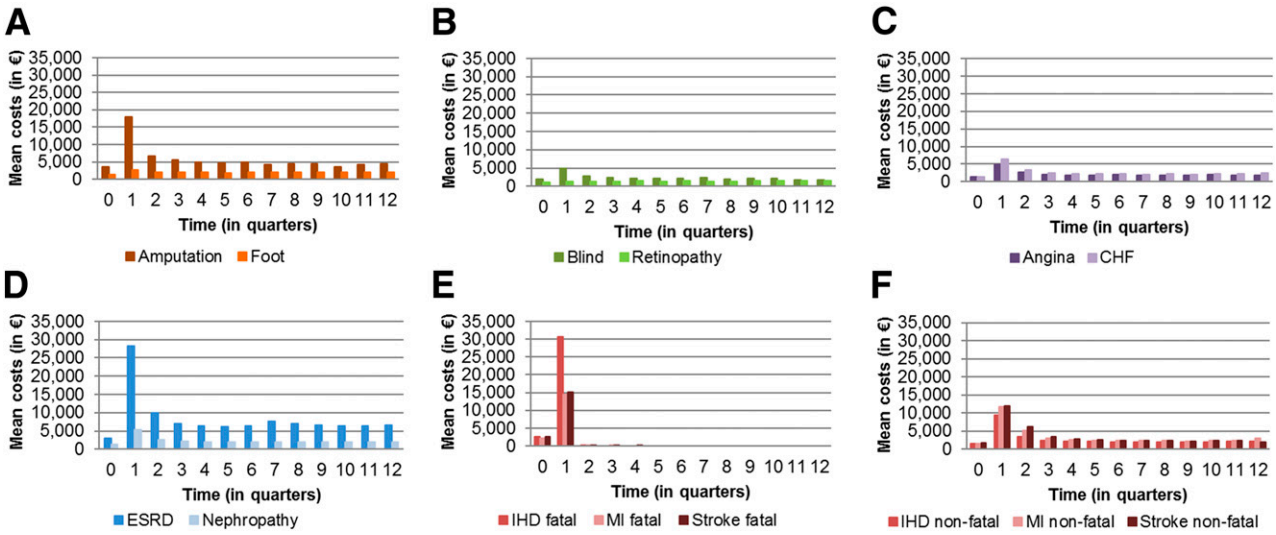

Figure 2—Distribution of raw total costs before and after the occurrence of acute events or onset of chronic complications in quarterly intervals. Costs were not standardized and refer to the patients who were alive or died in the same quarter during the follow-up period (see Supplementary Fig. 2 for further details). Time zero is the mean over patients and quarters without complication; "1" is the quarter where the complication occurs/starts. *A*: Lower-extremity complications. *B*: Eye complications. *C*: Chronic heart complications. *D*: Renal complications. *E*: Acute fatal macrovascular complications. *F*: Acute nonfatal macrovascular complications.

of other fatal IHD were also estimated to be very high, but the SE is the highest because of the small number of patients. It is also noticeable that men have higher costs in most age-groups in the event quarter for macrovascular complications, severe renal complications, and LEA. The differences range from ~5% higher costs for LEA to >80% for fatal MI and more than double for fatal IHD. For acute macrovascular complications, sex differences are higher for fatal than for nonfatal events. Women, in contrast, have higher costs in the first quarter of microvascular complications such as diabetic foot, retinopathy, and blindness, and for macrovascular complications only in specific age-groups. The differences here range from 20% to 30% higher costs for blindness to >50% for retinopathy in the younger age-groups. For retinopathy and diabetic foot, sex differences in costs decrease with higher age-group or even reverse, as for diabetic foot complications. In addition, women also have higher costs in the follow-up quarters for the majority of complications except ESRD. This especially applies to the younger age-groups, whereas the effect often declines in older age-groups. Additional cross-validation was performed by relatively comparing our results with the UKPDS Outcomes Model (version 2) based on the example of a 70- to 79-year-old patient (see Supplementary Table 9).

Sensitivity Analysis

In the sensitivity analysis using winsorization, estimates have generally not changed greatly (results are available on request). The largest changes of 11%–42% reduced costs were mainly related to those complications that are known to be rather rare and expensive (e.g., ESRD, amputation, and fatal macrovascular events).

CONCLUSIONS

There is, to our knowledge, no comparable study that provides an overall picture of the impact of many diabetes-related complications on health care costs in Germany. This study is, therefore, the first providing sufficiently detailed information on the real-life costs of patients with type 2 diabetes for a variety of acute or chronic microvascular and macrovascular complications based on nationwide German claims data for 2012–2015. The results not only show that costs are increased in the quarter in which the event/disease occurs but also show that they continue to be elevated in subsequent years. Second, it becomes apparent that women and men in different age-groups differ in the costs of their complications.

Comparison and Cross-Validation With Other Studies

In 2012, the standardized prevalence of clear type 2 diabetes cases (ICD E11) was lower compared with the estimate of Tamayo et al. (13) for 2010 (5.6% vs. 7.1%). This is in line with a comparison study between different health insurance funds in Germany that resulted in a prevalence of 5.8% for the TK compared with 6.9% overall (32). However, given knowledge about the large numbers of misdiagnosed diabetes cases, the total diabetes prevalence of 8.5% and 7.0% for men and women is overall comparable with other literature (2,33). This also reflects the importance of choosing an appropriate selection strategy for potential type 2 diabetes cases. The proportion of patients who had no antidiabetes treatment at baseline was relatively high (37.9%) compared with the literature (20% for Germany) (34). However, the widely published Costs of Diabetes Mellitus (CoDiM) study also reported a higher percentage of 29.4%, which is comparable to our findings for DMP participants (28.6%) (35). The reason for this higher value cannot be fully determined; it could be because of a healthier patient sample, improved disease monitoring, or false-positive or less severe/prediabetic cases.

Total raw mean costs of €4,688 (2013) are in the same range as reported in other studies, including the CoDiM study and others (€5,993 and €4,377 in 2010, respectively) (21,36). We also cross-validated our results by comparing calculated cost factors for each complication (relative to no complications) with the UKPDS Outcomes Model based on the example of a 70- to 79-year-old patient. Generally,

Table 2—Effects of acute events and chronic type 2 diabetes complications on total costs per quarter in GEE normal regression

Variable	Coefficient estimate (SE)		
Constant	779.7*** (7.9)		
Sex: male (Ref = female)	−57.1*** (6.3)		
Age-group (Ref = 70–79 years), years†			
<50	−128.3*** (12.6)		
50–59	−116.3*** (9.2)		
60–69	−69.2*** (8.4)		
>80	−195.1*** (12.0)		
	Coefficient estimate (SE)		
Event/condition (Ref = no)	Quarter/time of event	<1 year after the event‡	>1 year after the event‡
Diabetic foot	639.3*** (30.8)	369.2*** (17.0)	356.0*** (23.0)
Amputation	13,630.3*** (482.0)	2,665.9*** (168.8)	1,967.9*** (319.3)
Retinopathy	17.5 (16.0)	27.2 (14.2)	39.1* (18.0)
Blindness	2,279.9 (177.3)	487.1 (67.6)	316.2 (80.3)
Nephropathy	2,699.3*** (47.2)	702.0*** (19.3)	432.7*** (21.4)
ESRD	22,037.6*** (700.4)	5,476.4*** (195.5)	4,605.9*** (293.0)
Fatal MI	8,046.2*** (950.8)	NA	NA
Nonfatal MI	7,381.7*** (152.6)	820.8*** (73.5)	220.6** (71.3)
Fatal IHD	20,288.4*** (5,251.3)	NA	NA
Nonfatal IHD	5,894.9*** (141.4)	523.3*** (69.9)	171.2*** (52.3)
CHF	3,258.5*** (55.3)	868.7*** (24.0)	549.7*** (24.4)
Fatal stroke	10,522.9*** (903.5)	NA	NA
Nonfatal stroke	9,115.6*** (155.5)	2,168.8*** (88.7)	642.6*** (54.8)
Angina pectoris	2,041.9*** (50.4)	242.2*** (27.6)	106.3** (35.7)
Death for other reasons	5,589.0*** (124.2)	NA	NA
History in 2012 (Ref = no)	Coefficient estimate (SE)		
Diabetic foot	372.5*** (13.9)		
Amputation	2,017.4*** (171.1)		
Retinopathy	63.2*** (9.3)		
Blindness	196.2*** (47.5)		
Nephropathy	408.8*** (11.1)		
ESRD	6,902.3*** (164.3)		
Nonfatal MI	52.1 (46.3)		
Nonfatal IHD	566.1*** (25.4)		
CHF	532.6*** (12.8)		
Angina pectoris	−11.6 (19.4)		
Nonfatal stroke	635.2*** (46.5)		
Number of observations	3,663,240		
Number of patients	316,220		

NA, not applicable; Ref, reference. *P <0.05. **P <0.01. ***P <0.001. †The interactions between age and sex as well as threefold interactions with complications are omitted here for visibility reasons. The extended model as well as estimated costs by age-group and sex can be found in Supplementary Tables 7 and 8. ‡"Event" refers to the quarter when the diabetes complication first occurred/started.

a reasonable level of congruence was observed, with greater deviations for IHD and diabetic foot. However, greater uncertainty has to be considered in our regression model regarding IHD. In the publication by Alva et al. (22) on the updated cost estimations in the UKPDS model, female patients in most age-groups and complications were assumed to have higher costs (except for ESRD and foot ulcer, where the same costs are assumed in the model). When considering interactions between age, sex, and complications, it was noticeable that our study reveals more differences between men and women. Accordingly, in the event quarter, men had higher costs in most age-groups for ESRD, LEA, and macrovascular complications, whereas women had higher costs for other microvascular complications. Also, women had higher costs in the follow-up quarters for the majority of complications except ESRD. However, because of a lower number of cases in some age-groups, interaction estimates do not always show significant effects and should be interpreted with caution. Important reasons for these sex differences in health care costs could be potentially different causes of the disease (e.g., hemorrhagic versus ischemic stroke and role of psychological factors in women), different severity, or differences in disease management (e.g., less invasive treatments in women with MI) (37). From a methodological point of view, it is also important to consider the age distribution in the different age-groups. Mean age is the same in the middle age-groups, whereas women are 2 years younger than men in the age-group <50 years (44 vs. 42 years) and 1 year older than en in the group >80 years (83 vs. 84 years).

Strengths and Weaknesses of This Study

This study uses the method of regression analysis to provide reliable estimates of

costs associated with different type 2 diabetes complications, adjusted for age, sex, a large set of preexisting complications at baseline, and other two- or three-factor interactions. It was considered to not control for other chronic comorbidities for several reasons, which might have an effect on the results. First, to avoid overadjustment, it would be a crucial point to identify functionally fully independent conditions that are unrelated to the complications of interest. This is especially difficult, since diabetes and its complications are affecting the whole body system. Second, we have good evidence that age is the main predictor of comorbidity (38). Third, we explored the potential bias using the example of obesity, showing that most of the estimates do not differ much at all or at least not significantly.

The analysis itself was based on health insurance data that can be regarded as the best available data source for health care costs in Germany; however, inherent advantages and disadvantages must be considered. First, the representativeness of the data has to be assessed. Despite the high population coverage and the nationwide scope of the TK database, a small selection bias cannot be excluded for any of the insurance providers (32). In this case, the age distribution of the TK population is slightly skewed toward younger people (compared with the general population); however, the mean age of patients with diabetes in our population is comparable with other studies (35).

Second, there are only limited clinical data covered by health claims data. This means that the identification of complications is relying on accurate clinical diagnoses and clinical history information at baseline and that the length of diabetes is unknown. However, regarding the latter point, most diabetes models by their nature require mean cost values as input parameters for practical modeling reasons. What we also have is relatively robust information on the severity of diabetes at baseline (e.g., from treatment type, aDCSI score, and presence of certain risk factors). In addition, we use the information on the history of complications at baseline as an indicator to cope with not having prospective clinical data from newly diagnosed patients with diabetes (as in the UKPDS). It is important that most of these clinical trials are very expensive to conduct and are often still too short to measure the complication costs for many chronic diseases (39). When focusing on cost data, a major strength of this study can therefore be seen in the real-world setting in which the costs are incurred by a large population experiencing natural heterogeneity. The sample size of >300,000 patients with type 2 diabetes also guaranteed the statistical power to investigate rather rare complications (i.e., ESRD, blindness, and amputation). In addition, claims data are not subjected to recall bias, which can be an issue in clinical trials. Finally, another strength of this study is the reference to international diabetes models, which allows better cross-validation. A lack of a sharp boundary between diabetes-related and -unrelated complications remains an important aspect. This applies, for instance, to tumors, injury/poisoning, or psychiatric and psychological illnesses. As for the injuries, it cannot be ruled out that peripheral neuropathy and foot deformities are associated with increased risk of injuries. This is why no diseases beyond type 1 and other diabetes were excluded here. In addition, the relatively large sample size already ensures the stability of the results and that certain groups are not overrepresented by chance.

Summary and Implications

Type 2 diabetes complications have a significant impact on total health care costs in the SHI system, with varying size dependent on age, sex, and type of complication. Our comprehensive estimates may further inform diabetes models and support politicians and health care actors in evaluating the optimal resource allocation across different prevention and intervention programs for the management of type 2 diabetes complications. For high-frequency complications, it is of particular interest for future studies to investigate a deeper analysis of interactions between complications and the importance of the severity of complications. It is also to be expected that this study will motivate future research in the field of diabetes modeling in Germany.

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