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IDF Diabetes Atlas: Global estimates of diabetes prevalence for 2017 and projections for 2045

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ABSTRACT

Introduction: Since the year 2000, IDF has been measuring the prevalence of diabetes nationally, regionally and globally.
Aim: To produce estimates of the global burden of diabetes and its impact for 2017 and projections for 2045.
Methods: A systematic literature review was conducted to identify published studies on the prevalence of diabetes, impaired glucose tolerance and hyperglycaemia in pregnancy in the period from 1990 to 2016. The highest quality studies on diabetes prevalence were selected for each country. A logistic regression model was used to generate age-specific prevalence estimates or each country. Estimates for countries without data were extrapolated from similar countries.
Results: It was estimated that in 2017 there are 451 million (age 18–99 years) people with diabetes worldwide. These figures were expected to increase to 693 million) by 2045. It was estimated that almost half of all people (49.7%) living with diabetes are undiagnosed. Moreover, there was an estimated 374 million people with impaired glucose tolerance (IGT) and it was projected that almost 21.3 million live births to women were affected by some form of hyperglycaemia in pregnancy. In 2017, approximately 5 million deaths worldwide were attributable to diabetes in the 20–99 years age range. The global healthcare expenditure on people with diabetes was estimated to be USD 850 billion in 2017.
Conclusion: The new estimates of diabetes prevalence, deaths attributable to diabetes and healthcare expenditure due to diabetes present a large social, financial and health system burden across the world.

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1. Introduction

Diabetes mellitus (DM) describes a group of metabolic disorders characterised by high blood glucose levels. People with diabetes have an increased risk of developing a number of serious life-threatening health problems resulting in higher medical care costs, reduced quality of life and increased mortality. [1]. Persistently high blood glucose levels cause generalized vascular damage affecting the heart, eyes, kidneys and nerves and resulting in various complications [2].

The global prevalence of diabetes and impaired glucose tolerance in adults has been increasing over recent decades [3–6]. The pace of change in diabetes prevalence in many countries and regions has been boosted by rapid urbanisation and dramatic changes towards sedentary lifestyle [7]. Accurate estimates of the current and future burden of diabetes are necessary for allocating community and health resources, and to create strategies to counteract these rising trends.

In 1980, the World Health Organization (WHO) estimated that there were 108 million people living with diabetes and this number increased fourfold in 2014 estimates [8]. The International Diabetes Federation (IDF) estimated the global prevalence to be 151 million in 2000 [9], 194 million in 2003 [10], 246 million in 2006 [11], 285 million in 2009 [12], 366 million in 2011 [13], 382 million in 2013 [14] and 415 million in 2015 [15]. Each estimate was based on the latest data available. This paper provides estimates of the worldwide and regional impact of diabetes for 2017 and 2045, based on the most recent epidemiological data.

2. Methodology

2.1. *Study selection*

A literature search of PubMed and Google Scholar for data sources reporting the age-specific prevalence of diabetes was conducted from 1990 to 2016 using the search terms: 'diabetes' OR 'impaired glucose tolerance' AND 'prevalence' AND ⟨country name⟩ OR ⟨region/continent⟩.

In addition, data sources were gathered from national health surveys conducted by governments, or international organisations including reports from the WHO Stepwise approach to Surveillance (STEPS studies). Relevant citations from published literature were also reviewed, and investigators within the IDF network were consulted to identify additional data sources. If the identified studies did not contain at least three age-groups for adults, enquiries were sent to corresponding authors with a request to provide additional information or they were excluded.

Diabetes researchers in each of the seven IDF regions were also contacted and requested to provide information on the prevalence of diabetes for countries within their region. The seven IDF Regions (Africa; Europe; Middle East and North Africa; North America and the Caribbean; South and Central America; South-East Asia; and the Western Pacific) were based on the six WHO Member States groups, however, the America WHO region is divided into two parts: North America and Caribbean Region and South and Central America Region. In addition, information was obtained through the IDF volunteer network and member associations.

After extracting the methodological information from studies, they were classified according to the following criteria: method of diagnosis (e.g. fasting blood glucose, oral glucose tolerance tests, glycated haemoglobin (HbA1c), self-report, medical record, random blood glucose, glycosuria); sample size; representation (e.g. nationally representative, regionally representative, single city or village, single ethnic group or cohort); year of the survey; and type of publication (e.g. peer-reviewed publication, national health survey, STEPS studies, personal communication).

Studies were excluded if they (i) did not include sufficient methodological information for characterisation, (ii) did not provide enough data on age-specific prevalence of diabetes, (iii) were based only on pharmacologically-treated diabetes, (iv) were conducted in hospital or clinic-based settings, or (v) were conducted before 1990. Furthermore, studies reporting only the prevalence of type 1 diabetes, or newly diagnosed diabetes were also excluded.

A scoring system was developed using the Analytic Hierarchy Process [16], which allows the comparison of different parameters (e.g. study type versus type of publication) to create a system of weights, whereby each criterion for characterisation receives a corresponding score reflecting the quality of the study (Fig. 1). Experts from the IDF network were asked to complete preferences charts, and these preferences were used to assign a value for each pairwise comparison (e.g. age of the data source vs method of diagnosis). When there was disagreement among respondents, a median value was used. Those pairwise comparisons were then inserted into a comparison matrix and assigned a priority weight using matrix algebra for each study characteristic. The new weights of each study characteristic were calculated on this basis using the Analytic Hierarchy Process, each study was given a score, with higher scores indicating better quality.

The histogram of the scores of all studies show that 60% of all studies have a score above 0.29, and 50% of all studies are above score 0.33. The value of 0.29 was chosen as a threshold for inclusion in order to include more than half of the studies (60%). [17]. All data sources scoring below this threshold of 0.29 were rejected. The highest scoring study for each country was selected together with other studies within 0.1 score range from the highest scoring study, and the rest of the studies beyond 0.1 score range were excluded.

In countries where more than one study was selected, the age-specific prevalence of diabetes was calculated as the weighted average of the contributing studies, with each study's contribution being weighted by its quality score from the analytic hierarchy process.

If no suitable studies were available for a country or territory, estimates were based on available data from countries matched by geographic location, World Bank income group, ethnicity, language and IDF Region. Income groups were taken from the updated World Bank's 2017 classification of the world's economies [18] and clustered into three groups (low income countries; middle income countries; and high income countries), based on estimates of gross national income per capita for the previous calendar year. Data on languages and ethnicities were derived from the Central Intelligence Agency World Factbook [19].

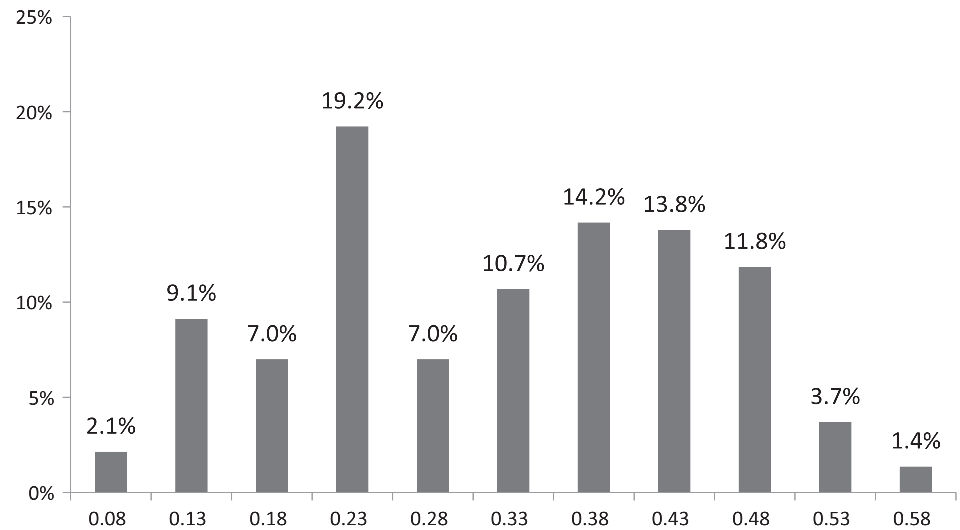

Fig. 1 – Histogram of the density of the study scores for all studies.

2.2. *Estimates of diabetes, impaired glucose tolerance, and hyperglycaemia in pregnancy*

Analyses were conducted using the R statistical program version 3.1.0 [20]. The age- and sex-specific prevalence of diabetes was calculated for urban and rural settings for each country. Logistic regression was used to generate smoothed sex- and age-specific prevalence estimates for adults 20–79 years and 18–99 years after data were extracted. The regression used age (as midpoint of each age-group) and the quadratic of age as separate independent variables for each subgroup (sex- and urban/rural setting- related) if available. The quadratic term was included to allow for a drop in diabetes prevalence for the oldest age groups. For some sources, where a sample size in a single group was less than 50, point adjustments were made by combining age groups to reduce variability.

Where primary data were not stratified by urban and rural status, a ratio was applied to estimate the proportion of diabetes for each setting, which was derived from aggregated data available within the same IDF region together with the percentage urbanisation by country available from the UN Population Division Urbanisation Prospects [21]. For high-income counties, the urban to rural ratio was assumed to be 1.0.

As these figures are only estimates, confidence intervals were calculated to reflect the range in which the "true" prevalence of diabetes is likely to lie, with a 95% probability. To estimate confidence intervals in the prevalence estimates and their magnitude, two separate analyses were performed: (1) a simulation study to assess raw data uncertainty, where about 1000 random samples were drawn inside of the 95% confidence interval range for each raw point estimate given in the data sources. These samples were then used in the IDF estimation procedure as conducted for the original data. (2) A bootstrap analysis of the sensitivity of the global prevalence estimate to the study selection process. In a loop, one study at a time was randomly removed from the list, and the global prevalence was calculated from the remaining studies. Wider confidence intervals indicated that the estimates were based on less reliable data sources [22].

The calculated age-, sex- and setting-specific estimates were then multiplied by corresponding population estimates for 2017, published by the United Nations [23] for each of the 221 countries and territories to generate estimates of cases of diabetes in adults aged 20–79 years and 18–99 years. Since UN does not proved age and sex specific population for countries and territories with population smaller than 90,000, the regional level ratio between age and sex specific population and total population were calculated in order to get the age and sex specific population of those countries. The seven regions are: Eastern Africa, Southern Europe, Western Europe, Caribbean, Norther America, Micronesia, Polynesia. To predict the number of people with diabetes for 2045, the middle population projections for 2045 from the United Nations Population Division were used [23]. The 2045 diabetes prevalence projections accounted for changes in population age structure and urbanisation, but did not explicitly include changes in the prevalence of diabetes or any other diabetes risk factors. Two different prevalence estimates were produced for each country and region: country-standardised and world-standardised prevalence. Country-standardised prevalence was calculated by standardising the prevalence to the age and sex distribution of the relevant country. This measurement provides the most useful way of assessing the impact of diabetes for each country or region. However, because the prevalence of diabetes increases with age, it cannot be used for comparing risk of diabetes between countries or regions, which have different age structures. World-standardised prevalence estimates were produced by standardising each country's prevalence to the same 2001 WHO Standard Population [24]. This removed the differences of age structure between countries and regions, and made this measurement suitable for making comparisons.

The number of people with diabetes for each of the seven IDF Regions and World Bank income group were calculated by aggregating the numbers of people with diabetes for each country within the respective regions. Global estimates were calculated by aggregating the total number of cases of diabetes for each country.

The same methodology was employed for impaired glucose tolerance estimates for 2017 and 2045. Estimates for hyperglycaemia in pregnancy and gestational diabetes were based on methodology previously described [25].

2.3. *Estimates for undiagnosed diabetes*

Undiagnosed diabetes cases and estimated ratios of the proportion of undiagnosed cases to the total number of cases were also collected from data sources, when available. This estimation procedure also included a data source selection procedure, where appropriate studies were chosen using the analytic hierarchy process, similar to the methods described above.

Since 2015, the IDF regional-level and World Bank income group-level effects on undiagnosed diabetes have been estimated by random-effect generalised linear regression, with weights corresponding to the quality score of the studies. The country-specific effect was generally assumed to be unknown and driven by latent variables to control for unobserved heterogeneity. The Durbin-Watson statistic was used to detect the presence of autocorrelation and check if the model was appropriate. The final model estimated undiagnosed diabetes by using studies from that country (if applicable), as well as studies from countries within the same IDF Region and World Bank income group, with weights corresponding to the quality score of the study [26].

2.4. *Diabetes health expenditure estimates*

The estimates of total healthcare expenditures on diabetes, and the mean healthcare expenditures per person with diabetes, expressed in both US Dollars (USD) and International Dollars (ID), were calculated using methodology previously described [27]. This method assumes that the healthcare expenditure for people with diabetes is, on average, twice the health expenditure for people without diabetes.

International Dollars are a hypothetical currency for which one International Dollar has the same purchasing power in the country of interest as has one United States Dollar in the United States of America at a given point in time. International Dollars can be used to make comparisons both between regions and over time. Purchasing power parity can be used as conversion factor to convert different currencies from different countries into the common currency unit of International Dollars.

2.5. *Diabetes mortality estimates*

The methods to derive mortality estimates have been previously described [28,29]. Briefly, the number of deaths attributable to diabetes used the following inputs: WHO life tables for 2010 and 2015 for the expected number of deaths among 20–79 and 20–99 age groups; country-specific diabetes prevalence by age and sex for the year 2017; age- and sex-specific relative risks of death for persons with diabetes (aged 20–79 and 20–99 years) compared to those without diabetes.

These inputs were used to model the estimates using Miettinen's formula for the population-attributable fraction and to calculate the number of deaths attributable to diabetes in people who are aged 20–79 years and 20–99 years.

New sources about the diabetes mortality relative risk ratio (RR) were identified in several countries and were then used for estimation of the diabetes mortality via extrapolation to the region. A Saudi Arabian study [30] was used to update high income countries (HIC) in the Middle East and North Africa (MENA) region, a Korean study [31] was used to update HIC in the Western Pacific (WP) region and an Australian study [32] was used to update the data for the U.S., Canada, New Zealand and HIC in Western Europe. Furthermore, a Latvian study [33] was chosen to update HIC in Eastern Europe; a study from China [34] was used to update middle-income countries (MIC) in the WP region; and a study from Mexico was used to update MIC in the North America and Caribbean (NAC) region [35]. A study from China was used to update RR for people aged 70–79 years [34]. Similarly, a study from Mexico was used to update RR for people aged 75–84 years [35]. Due to a lack of age specific total mortality data in WHO life table 2015, updates for total mortality were available only in the age groups of "50–59 and "60–69" compared to the estimates in the previous edition and for the remaining age groups the total mortality from 2010 was used.

3. Results

3.1. *Study selection*

The literature review identified 613 data sources representing 163 countries. Of these, 221 data sources were selected based on the analytic hierarchy process, representing 131 countries. All studies in the selected list were population-based, and 71 used the oral glucose tolerance test as a method of diagnosis. In total, 90 country estimates were based on extrapolation. In total, 215 out of 221 studies were nationally-representative. The complete list of data sources selected to produce the estimates can be found at www.diabetesatlas.org.

The South-East Asia Region had the highest proportion of original data sources for countries within the region (85.7%). Original data sources were available from 76.2% of countries in the Middle East and North Africa Region, 75% in the South and Central America Region, 71.8% in the Western Pacific Region, 61.4% of countries in the Europe Region, and 50% in the North America and Caribbean Region. The Africa Region had the lowest proportion of countries with original data sources, at only 34.7%.

The majority of countries did not have data sources for IGT, GDM and undiagnosed diabetes. Only 60 data sources from 47 countries were selected for IGT estimates. Only 37 countries had data sources for GDM. Only 123 studies from 70 countries were selected for the estimation of undiagnosed diabetes.

3.2. *Prevalence estimates of diabetes*

Among adults aged 20–79 years in 2017 there was an estimated 425 (confidence interval (CI) 346–545) million cases (8.8% (CI 7.2–11.3%) of diabetes. By expanding the age range to 18–99 years, this number rises to 451 (CI 367–585) million

(8.4% (CI 7.0–11.2%)) cases of diabetes. For 2045, these numbers are expected to increase. For the age group 20–79 years, it is estimated that 629 (CI 477–809) million people, equalling to 9.9% (CI 7.5–12.7%) of the population, will be living with diabetes. This number rises to an estimated 693 (CI 522–903) million people (9.9% (CI 7.5–12.9%)) living with diabetes, when expanding the age range to 18–99 years.

There were differences found in diabetes prevalence by age group, gender, World Bank income group and geographical region. In high-income countries, diabetes prevalence peaked (22%) in the 75–79 age group and in middle-income countries among the 60–74 age groups (19%). In low-income countries, the prevalence of diabetes peaked (8%) among the 55–64 age group. The prevalence of diabetes among 65–69 year olds was 3 times higher in high-income countries compared to low income countries (Fig. 2).

The prevalence of diabetes among women (18–99 years) in 2017 was estimated to be 8.4%, which is lower than in men (8.9%). There were about 12.3 million more men (231.7 million) than women (219.3 million) living with diabetes. It is expected that diabetes prevalence for both men and women will rise to 9.9% in 2045. Fig. 3 shows that for men the diabetes prevalence peaked at the age of 65–69 years, while for women it peaked at the age of 70–79 years. Moreover, nearly two thirds of people with diabetes (18–99 years) are living in urban environments (298 million) compared to one third in rural areas (153 million).

The highest age-adjusted diabetes prevalence in adults (18–99 years) was found in the North American and Caribbean Region (NAC) at 10.8% (CI 9.1–12.3%), while the lowest was in the Africa Region (AFR) at 4.2% (CI 2.7–7.7%) (Fig. 4). However, the largest number of people living with diabetes was found in the Western Pacific Region (WP), where there were 168.4 (CI 149.7–210.9) million in the age group 18–99 years (Fig. 4). This makes the Western Pacific region home to 37% of the total global diabetes population. Globally, about 79% of people living with diabetes live in low- and middle-income countries. (Fig. 5). Detailed estimates for each of the 221 included countries and territories can be found online at www.diabetesatlas.org.

3.3. *Prevalence estimates of undiagnosed diabetes*

Almost half of all people (49.7%) living with diabetes were undiagnosed in 2017, counting for over 224 million adults (18–99 years). The highest percentage was found in the Africa region where 69.2% of all cases were estimated to be undiagnosed. The South-East Asia (SEA) and Western Pacific Regions were estimated to have more than 50% of cases being undiagnosed (SEA 57.5%, WP 54%). The lowest proportion of undiagnosed diabetes were estimated in the North America and Caribbean Region (37.6%) and the Europe Region (37.8%) (Fig. 6). The highest proportion of undiagnosed diabetes cases was in low income countries (76.5%), however, the vast majority of undiagnosed people with diabetes were living in middle income countries, comprising 177.6 (CI 150.2–246) million people [18].

3.4. *Prevalence estimates of impaired glucose intolerance*

Worldwide in 2017, there were an estimated 374 (CI 246.3–623.9) million people, equalling 7.7% (CI 4.7–12.0%) of the world population, who were between 18 and 99 years and have impaired glucose tolerance (IGT). The majority (69.2%) of these people live in low- and middle-income countries. The number is projected to increase to 587 (CI 384.4–992.7) million adults (18–99 years) by 2045, equalling 8.4% (CI 5.5–14.2%) of the adult population. The prevalence of IGT increased steadily with the age-group, being lowest in the youngest group and highest in the oldest group (Fig. 7). Almost half (47.8%) of all adults (18–99 years) with IGT are under the age of 50. The North American and Caribbean Region has the highest IGT prevalence (13.6% age-adjusted) and the South East Asia Region has the lowest (3.4% age adjusted).

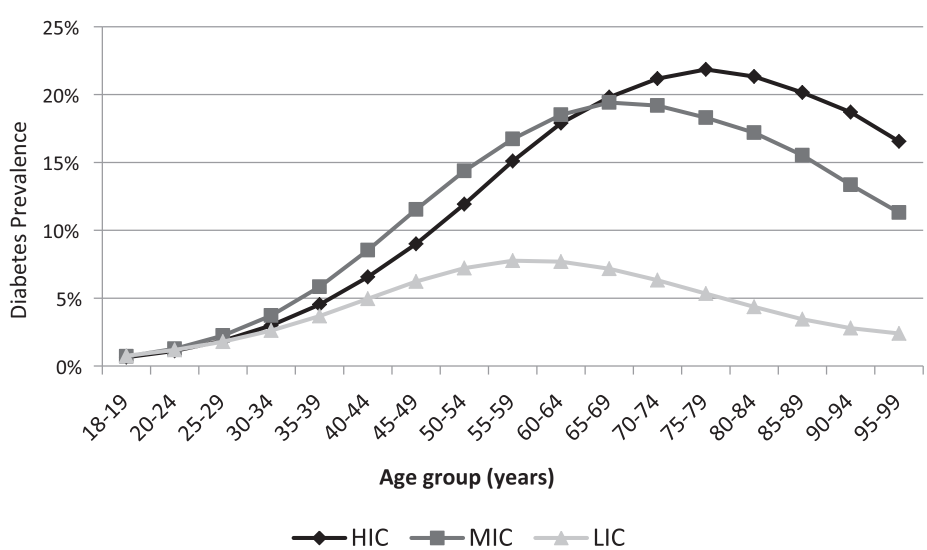

Fig. 2 – Prevalence (%) of diabetes by age and World Bank income group, 2017.

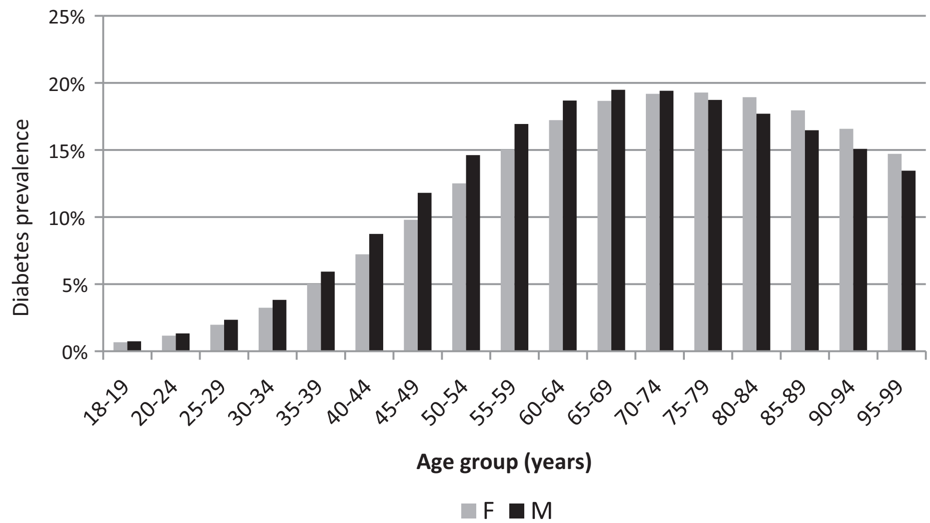

Fig. 3 – Prevalence (%) of people with diabetes by age and sex, 2017.

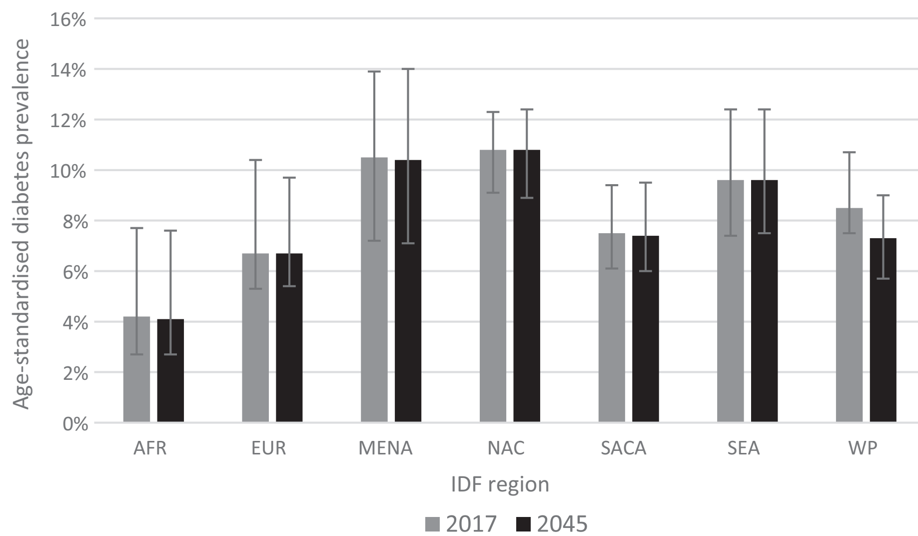

Fig. 4 – Age-standardised prevalence of diabetes per IDF region for 2017 and 2045 (18–99years).

3.5. *Prevalence estimates for hyperglycaemia in pregnancy*

It was estimated that, in 2017, around 21.3 million live births (16.2%) were affected by some form of hyperglycaemia in pregnancy. Approximately 18.4 million of these cases were due to gestational diabetes mellitus (GDM), accounting for 86.4% of all hyperglycaemia in pregnancy. Other cases were due to diabetes detected prior to the pregnancy (6.2%) and other types of diabetes, which were detected in pregnancy (7.4%). The South East Asia region had the highest raw prevalence of hyperglycaemia in pregnancy with 26.6%, while the Africa Region had the lowest with 9.5% (Fig. 8). Similar to the prevalence of diabetes and IGT, the vast majority of cases were in low- and middle-income countries. The prevalence of hyperglycaemia in pregnancy increases with age. While the prevalence was 9.8% for women in the age range of 20–24 years, the prevalence was 45.1% in women who are 45–49 years.

3.6. *Diabetes mortality estimates*

It was estimated that approximately 5.0 million (CI 4.0–6.4) deaths were attributable to diabetes among people aged 20–99 years in 2017. Hence, diabetes accounted for 9.9% of the global all-cause mortality among people within this age range. Over one third (36.5% or 1.8 million) of deaths attributable to diabetes occurred in people under the age of 60 years (Fig. 9). The highest proportion of all deaths attributable to diabetes occurring before the age of 60 is in the Africa region, at 73.7%. Nonetheless, the total number of deaths due to

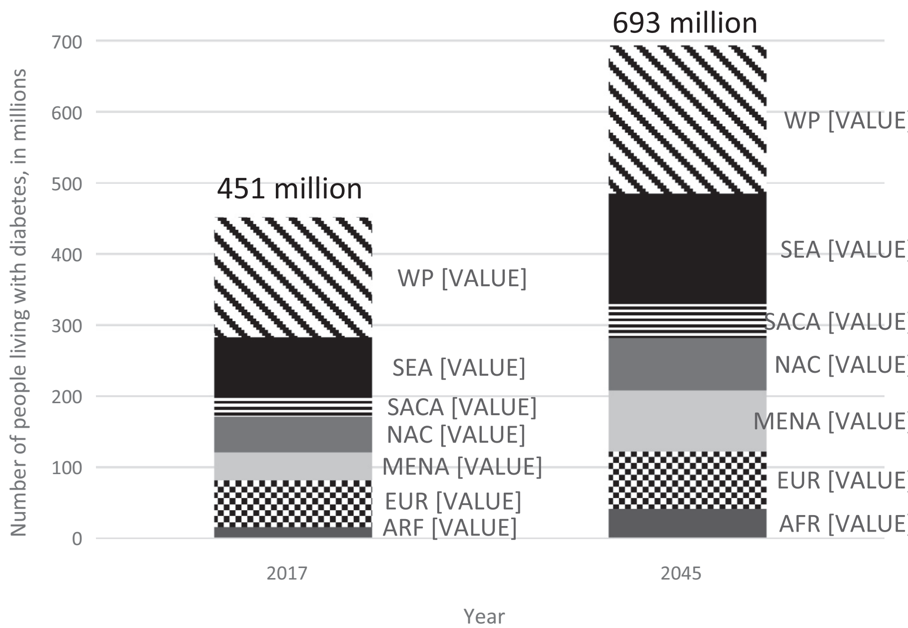

Fig. 5 – Total number of people living with diabetes by IDF region, 2017 and 2045 (18–99years).

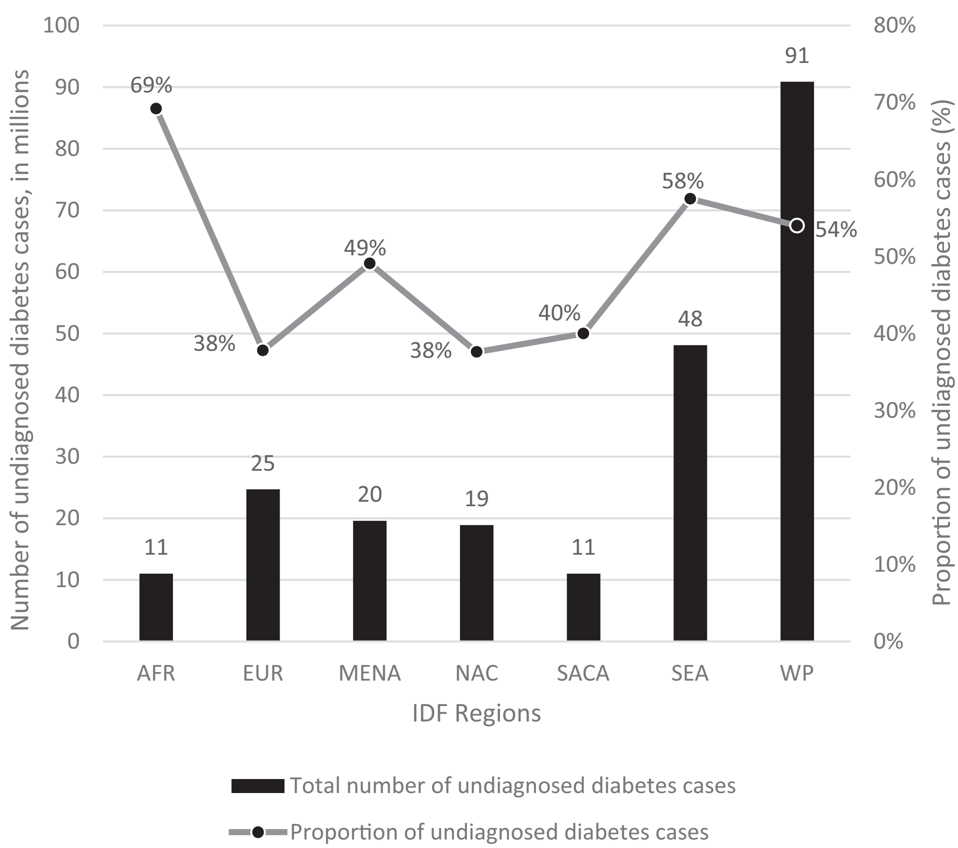

Fig. 6 – Number (in millions) and proportion (%) of undiagnosed diabetes cases per IDF region, 2017 (18–99years).

diabetes were the highest in the Western Pacific Region at 1.7 million (CI 1.5–2.0), and lowest in the South and Central America at 0.27 (CI 0.22–0.33) million.

3.7. *Diabetes healthcare expenditure estimates*

The total global healthcare expenditure due to diabetes for people aged 20–79 years was estimated at USD 727 billion in

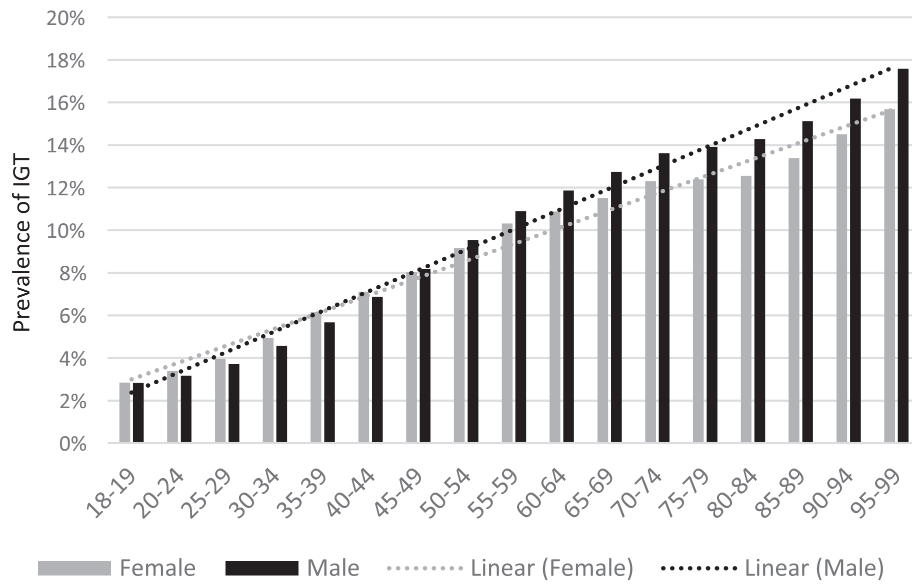

Fig. 7 – Prevalence (%) of impaired glucose tolerance (18–99years) by age and sex, 2017.

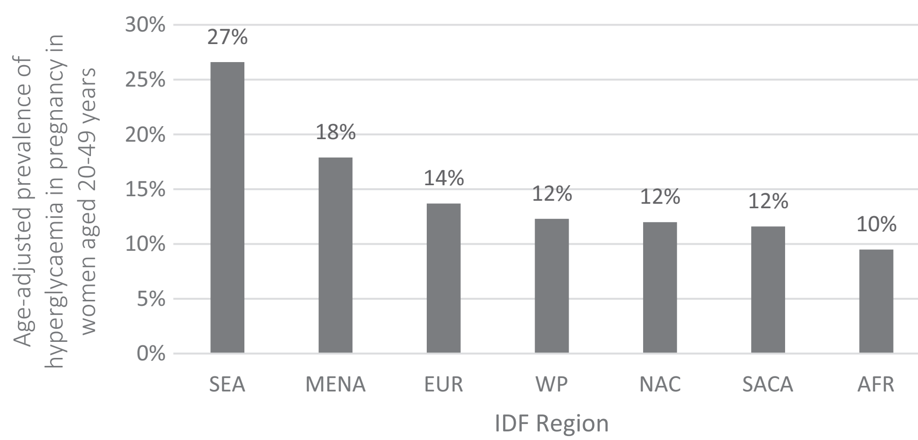

Fig. 8 – Age-adjusted prevalence (%) of hyperglycaemia in pregnancy in women aged 20–49years by IDF region, 2017.

2017. This number rises to USD 850 billion when expanding the age group to 18–99 years. By 2045, the global healthcare expenditure is expected to increase by 7% to USD 776 billion (20–79 years) and to USD 958 billion (18–99 years). The North American and Caribbean Region, with ID (International Dollar) 445 billion, had the highest healthcare expenditure on diabetes (18–99 years), and accounting for 52% of the total amount spent worldwide on diabetes in 2017. In addition, the Europe Region (ID 224 billion) and the Western Pacific Region (ID 199 billion) accounted for a large share of the total global spending. The other four regions were only responsible for 14% of the total global healthcare expenditure of diabetes (Fig. 10). Between 6% and 16% of the total healthcare budgets were allocated to diabetes, with the lowest being from the Africa Region, and the highest from the Middle East and North African Region. The largest expenditure was made for males in the age group 60–69 years (USD 127 billion), with the share being 7% higher than for women. In the groups 70–79 and 50–59 years, women accounted for higher expenditure than men. For 2045, it is expected that healthcare expenditure will remain stable for the population under the age of 50 years, but will increase by 37% for the population above 70 years due to the aging population. Mean healthcare expenditure per person was highest in the North American and Caribbean Region (ID 8929), and lowest in the South East Asia Region (ID 406) (Fig. 10).

4. Discussion

In 2017, 424.9 (CI 346.4–545.4) million people aged 20–79 years or 451 (CI 367.5–585.5) million people aged 18–99 years lived with diabetes. The number of people with diabetes aged 20–79 years was predicted to rise to 629 (CI 477.0–808.7) million or to 693 (CI 521.9–902.5) million among 18–99 years by 2045. The current estimate for 2017 among the age group of 20–79 is 281% higher than in the IDF Diabetes Atlas publication from 2000.

These estimates confirm the large and increasing burden of diabetes in the world, but with considerable variation across regions and income groups. People with diabetes in

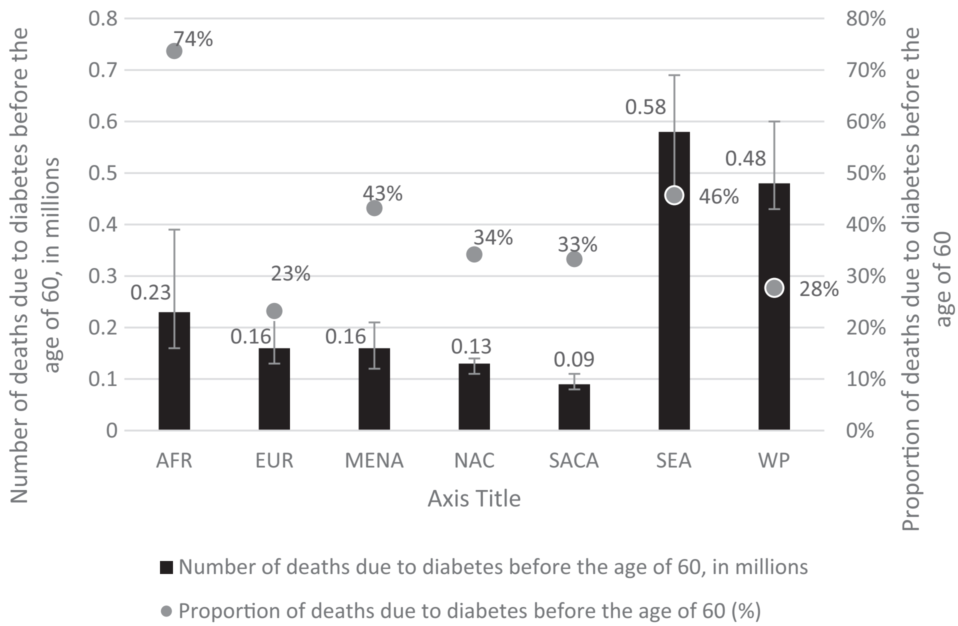

Fig. 9 – Number (in millions) and proportion (%) of all deaths attributable to diabetes that occur before the age of 60 per IDF regions, 2017.

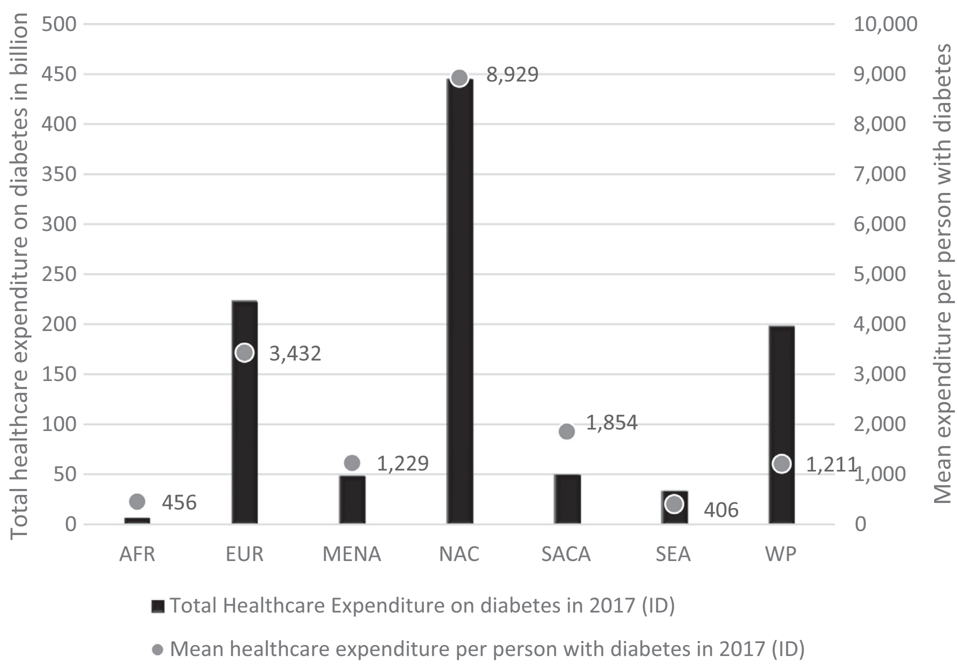

Fig. 10 – Economic burden of diabetes, 2017.

low- and middle-income countries are predominantly below the age of 65 (88% and 77% respectively), while almost half of the cases in high income countries are above this working age (44%). The likeliest explanation for the rise in diabetes is the socio-economic changes, such as changes towards sedentary lifestyle and higher rates of urbanisation, but also better healthcare improving the life expectancy of people with diabetes. Another explanation is also availability of newer data, which reports rising numbers in diabetes.

The prevalence estimates for 2017 were derived from the most recent available data with an effort made to minimise extrapolation outside countries in which data were collected. However, the estimates rely on both the availability and the quality of data sources.

The data sources used in the model had substantial differences in diagnostic methods, the age of study, sample size of the study, and type of data source. Despite efforts to select the highest quality studies for each country using the analytic hierarchy process, and to standardise estimates using logistic regression, it was still difficult to minimise the differences in country-level estimates that were due to methodological diversity. Thus, the variation in methods and standards are likely to have influenced the degree to which the estimates can be depended on to be accurate, and should be taken into account when making comparisons between countries.

The 2045 projections may be considered conservative, because they do not account for the changes in economic status of the countries or likely worsening of any diabetes risk factors, such as overweight [36], highest level of household education [37], household income food security [37], sugar availability [38], percent of total energy intake from sugars and sweeteners [39], impaired glucose tolerance [40], gestational diabetes [36], and other noncommunicable diseases [40].

It was not possible to estimate the number of adults with type 1 and type 2 diabetes separately, as most of the studies used did not report these groups independently.

The estimates of undiagnosed diabetes are derived from a small number of studies and therefore the design of these studies, and choices about extrapolation become more relevant, which can have a profound effect on the pooled proportion of undiagnosed diabetes applied to a country. There is also a considerable lack of population-based surveys based on fasting blood glucose or OGTT in high income countries where surveys of self-reported diabetes are abundant, affecting further the uncertainty of the estimates regarding undiagnosed diabetes.

The 95% confidence intervals around the "true" global prevalence of diabetes were estimated using a mixed method by combining the raw data uncertainty and the model's sensitivity to data source selection. However, by using only this "one-at-a-time" sensitivity to estimate confidence, the approach did not take into account any other potential sources of uncertainty, such as a Bayesian model (NCD Risk Factor Collaboration (NCD-RisC) [6]).

The major driver of diabetes costs is the treatment of the related complications, but we did not include the indirect costs, such as government benefits or days off work. Current estimates assume that costs for healthcare among people with diabetes are twice those in people without diabetes. The supporting evidence for this assumption is still limited.

The attributable-risk approach for mortality that we have used allows a more realistic estimate of the burden of mortality that is attributable to diabetes than does, for instance, reporting based on death certificates. However, the attributable-risk approach relies on the estimates of the age- and sex- specific relative risks of mortality in people with diabetes compared to those without, which were extracted from a small number of studies and then applied to other disparate populations. Additionally, other covariates such as rural or urban environment, time since diagnosis, or medications were not applied in the model [28].

We have focussed only on prevalence studies, though studies on incidence have the potential to provide more reliable information on a population's risk of developing diabetes. Currently, it is difficult to estimate the incidence of type 2 diabetes, because study size needs to be larger than for prevalence studies, and it can be difficult to account for undiagnosed diabetes. Nevertheless, estimates of incidence provide important information that cannot easily be derived from prevalence studies, and efforts to develop accurate incidence studies should be made.

5. Conclusion

The prevalence of diabetes in adults aged 18–99 years was estimated to be 8.4% in 2017 and predicted to rise to 9.9% in 2045.The high prevalence of diabetes has important social, financial and development implications especially in low- and middle-income countries. There is an increasingly urgent need for governments to implement policies to decrease the risk factors for type 2 diabetes and gestational diabetes, and ensure appropriate access to treatment for all people living with diabetes. The considerable gaps in data and in data quality about the burden of diabetes need to be addressed in order to more confidently develop policies.

Conflicts of interest

There is no conflict of interest.

REFERENCES

[1] Baena-Díez JM, Peñafiel J, Subirana I, et al. Risk of cause-specific death in individuals with diabetes: a competing risks analysis. Diabetes Care 2016;39(11):1987–95. https://doi.org/10.2337/dc16-0614.

[2] World Health Organization. Global health risks: mortality and burden of disease attributable to selected major risks. Geneva: Switzerland; 2009. Available at:Available from: <http://www.who.int/healthinfo/global_burden_disease/GlobalHealthRisks_report_full.pdf>.

[3] Shaw JE, Sicree RA, Zimmet PZ. Global estimates of the prevalence of diabetes for 2010 and 2030. Diabetes Res Clin Pract 2010;87(January (1)):4–14.

[4] Whiting DR, Guariguata L, Weil C, Shaw J. IDF Diabetes Atlas: global estimates of the prevalence of diabetes for 2011 and 2030. Diabetes Res Clin Pract 2011;94(December (3)):311–21.

[5] Ogurtsova K, da Rocha Fernandes JD, Huang Y, Linnenkamp U, Guariguata L, Cho NH, et al. IDF Diabetes Atlas: global estimates for the prevalence of diabetes for 2015 and 2040. Diabetes Res Clin Pract 2017;128:40–50. https://doi.org/10.1016/j.diabres.2017.03.024. Epub 2017 Mar 31.

[6] Guariguata L, Whiting DR, Hambleton I, Beagley J, Linnenkamp U, Shaw JE. Global estimates of diabetes prevalence for 2013 and projections for 2035. Diabetes Res Clin Pract 2014;103(2):137–49. https://doi.org/10.1016/j.diabres.2013.11.002. Epub 2013 Dec 1.

[7] Blas E, Kuru A, editors. Diabetes: equity and social determinants. In: Equity, social determinants and public health programmes. Geneva: World Health Organization; 2010.

[8] NCD Risk Factor Collaboration (NCD-RisC). Worldwide trends in diabetes since 1980: a pooled analysis of 751 population-based studies with 4*4 million participants. Lancet 1980;2016. https://doi.org/10.1016/S0140-6736(16)00618-8. published online April 7.

[9] International Diabetes Federation. IDF Diabetes Atlas. 1st ed. Brussels, Belgium: International Diabetes Federation; 2000.

[10] International Diabetes Federation. IDF Diabetes Atlas. 2nd ed. Brussels, Belgium: International Diabetes Federation; 2003.
[11] International Diabetes Federation. IDF Diabetes Atlas. 3rd ed. Brussels, Belgium: International Diabetes Federation; 2006.
[12] International Diabetes Federation. IDF Diabetes Atlas. 4th ed. Brussels, Belgium: International Diabetes Federation; 2009.
[13] International Diabetes Federation. IDF Diabetes Atlas. 5th ed. Brussels, Belgium: International Diabetes Federation; 2011.
[14] International Diabetes Federation. IDF Diabetes Atlas. 6th ed. Brussels, Belgium: International Diabetes Federation; 2013.
[15] International Diabetes Federation. IDF Diabetes Atlas. 7th ed. Brussels, Belgium: International Diabetes Federation; 2015.
[16] Saaty TL. Decision making with the analytic hierarchy process. Int J Serv Sci 2008;1:83–97. https://doi.org/10.1504/IJSSCI.2008.017590.
[17] Ogurtsova K, Guariguata L, Whiting D, Unwin N, Weil C, da Rocha Fernandes J., et al. Sensitivity analysis of the global diabetes prevalence estimate in the IDF Diabetes Atlas (Poster). In: International diabetes epidemiology group. Vancouver; 2015.
[18] World Bank Group. World bank country and lending groups. Data Help Desk; 2017.
[19] Central Intelligence Agency. Country profiles, World factbook. Fairfax, USA: Central Intelligence Agency; 2015.
[20] R Core Team. R: a language and environment for statistical computing. Vienna, Austria: R Foundation for Statisticalv Computing; 2012.
[21] United Nations, Department of Economic and Social Affairs, Population Division. World urbanization prospects: the 2014 revision. New York, USA: United Nations Population Division; 2014.
[22] Ogurtsova K, Guariguata L, Whiting D, Unwin N, Weil C, Fernandes JDR, et al. Incorporating uncertainty measurement in the International Diabetes Federation Diabetes Atlas methodology for estimating global and national prevalence of diabetes in adults (Poster). Arch Public Health 2015;73. https://doi.org/10.1186/2049-3258-73-S1-P31.
[23] United Nations, Department of Economic and Social Affairs, Population Division. World population prospects: the 2015 revision. New York, USA: World Population Prospects; 2015.
[24] Ahmad OB, Boschi-Pinto C, Lopez AD, Murray CJ, Lozano R, Inoue M. Age standardization of rates: a new WHO standard (GPE Discussion Paper Series: No. 31). Geneva, Switzerland: World Health Organization; 2001.
[25] Linnenkamp U, Guariguata L, Beagley J, Whiting DR, Cho NH. The IDF Diabetes Atlas methodology for estimating global prevalence of hyperglycaemia in pregnancy. Diabetes Res Clin Pract 2014;103:186–96. https://doi.org/10.1016/j.diabres.2013.11.004.
[26] Ogurtsova K, da Rocha Fernandes J, Cavan DMakaroff LEIDF Atlas Group. Global estimates for undiagnosed diabetes for the 2015 IDF diabetes Atlas: a revision of the methodology. New Orleans, USA: American Diabetes Association Scientific Sessions (Poster); 2016.
[27] da Rocha Fernandes J, Ogurtsova K, Linnenkamp U, Guariguata L, Seuring T, Zhang P, et al. IDF diabetes atlas estimates of 2014 global health expenditures on diabetes. Diabetes Res Clin Pract 2016;117:48–54. https://doi.org/10.1016/j.diabres.2016.04.016.
[28] IDF Diabetes Atlas Group. Update of mortality attributable to diabetes for the IDF Diabetes Atlas: estimates for the year 2011. Diabetes Res Clin Pract 2013;100:277–9. https://doi.org/10.1016/j.diabres.2013.02.005.
[29] Roglic G, Unwin N. Mortality attributable to diabetes: estimates for the year 2010. Diabetes Res Clin Pract 2010;87:15–9. https://doi.org/10.1016/j.diabres.2009.10.006.
[30] Al-Rubeaan K et al. All-cause mortality and its risk factors among type 1 and type 2 diabetes mellitus in a country facing diabetes epidemic. Diabetes Res Clin Pract 2016;118:130–9.
[31] Kang YM, Kim Y-J, Park J-Y, Lee WJ, Jung CH. Mortality and causes of death in a national sample of type 2 diabetic patients in Korea from 2002 to 2013. Cardiovasc Diabetol 2016;15.
[32] Harding JL et al. Mortality trends among people with type 1 and type 2 diabetes in Australia: 1997–2010. Diabetes Care 2014;37:2579–86.
[33] Pildava S, Strēle I, Briģis G. The mortality of patients with diabetes mellitus in Latvia 2000–2012. Med Kaunas Lith 2014;50:130–6.
[34] Bragg F et al. Association between diabetes and cause-specific mortality in rural and urban areas of China. JAMA 2017;317:280–9.
[35] Alegre-Díaz J et al. Diabetes and cause-specific mortality in Mexico City. N Engl J Med 2016;375:1961–71.
[36] Kaul P, Savu A, Nerenberg KA, Donovan LE, Chik CL, Ryan EA, et al. Impact of gestational diabetes mellitus and high maternal weight on the development of diabetes, hypertension and cardiovascular disease: a population-level analysis. Diabet Med J Br Diabet Assoc 2015;32:164–73. https://doi.org/10.1111/dme.12635.
[37] Rivera LA, Lebenbaum M, Rosella LC. The influence of socioeconomic status on future risk for developing Type 2 diabetes in the Canadian population between 2011 and 2022: differential associations by sex. Int J Equity Health 2015;14:101. https://doi.org/10.1186/s12939-015-0245-0.
[38] Basu S, Yoffe P, Hills N, Lustig RH. The relationship of sugar to population-level diabetes prevalence: an econometric analysis of repeated cross-sectional data. PLoS ONE 2013;8:e57873. https://doi.org/10.1371/journal.pone.0057873.
[39] Siegel KR, Echouffo-Tcheugui JB, Ali MK, Mehta NK, Narayan KM, Chetty V. Societal correlates of diabetes prevalence: an analysis across 94 countries. Diabetes Res Clin Pract 2012;96:76–83. https://doi.org/10.1016/j.diabres.2011.11.014.
[40] Razavian N, Blecker S, Schmidt AM, Smith-McLallen A, Nigam S, Sontag D. Population-level prediction of type 2 diabetes from claims data and analysis of risk factors. Big Data 2015;3:277–87. https://doi.org/10.1089/big.2015.0020.