National, regional, and global trends in fasting plasma glucose and diabetes prevalence since 1980: systematic analysis of health examination surveys and epidemiological studies with 370 country-years and 2·7 million participants

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Summary

Background Data for trends in glycaemia and diabetes prevalence are needed to understand the effects of diet and lifestyle within populations, assess the performance of interventions, and plan health services. No consistent and comparable global analysis of trends has been done. We estimated trends and their uncertainties in mean fasting plasma glucose (FPG) and diabetes prevalence for adults aged 25 years and older in 199 countries and territories.

Methods We obtained data from health examination surveys and epidemiological studies (370 country-years and 2·7 million participants). We converted systematically between different glycaemic metrics. For each sex, we used a Bayesian hierarchical model to estimate mean FPG and its uncertainty by age, country, and year, accounting for whether a study was nationally, subnationally, or community representative.

Findings In 2008, global age-standardised mean FPG was 5·50 mmol/L (95% uncertainty interval 5·37–5·63) for men and 5·42 mmol/L (5·29–5·54) for women, having risen by 0·07 mmol/L and 0·09 mmol/L per decade, respectively. Age-standardised adult diabetes prevalence was 9·8% (8·6–11·2) in men and 9·2% (8·0–10·5) in women in 2008, up from 8·3% (6·5–10·4) and 7·5% (5·8–9·6) in 1980. The number of people with diabetes increased from 153 (127–182) million in 1980, to 347 (314–382) million in 2008. We recorded almost no change in mean FPG in east and southeast Asia and central and eastern Europe. Oceania had the largest rise, and the highest mean FPG (6·09 mmol/L, 5·73–6·49 for men; 6·08 mmol/L, 5·72–6·46 for women) and diabetes prevalence (15·5%, 11·6–20·1 for men; and 15·9%, 12·1–20·5 for women) in 2008. Mean FPG and diabetes prevalence in 2008 were also high in south Asia, Latin America and the Caribbean, and central Asia, north Africa, and the Middle East. Mean FPG in 2008 was lowest in sub-Saharan Africa, east and southeast Asia, and high-income Asia-Pacific. In high-income subregions, western Europe had the smallest rise, 0·07 mmol/L per decade for men and 0·03 mmol/L per decade for women; North America had the largest rise, 0·18 mmol/L per decade for men and 0·14 mmol/L per decade for women.

Interpretation Glycaemia and diabetes are rising globally, driven both by population growth and ageing and by increasing age-specific prevalences. Effective preventive interventions are needed, and health systems should prepare to detect and manage diabetes and its sequelae.

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Introduction

Hyperglycaemia and diabetes are important causes of mortality and morbidity worldwide, through both direct clinical sequelae and increased mortality from cardiovascular and kidney diseases.[1–6] With rising overweight and obesity,[7] concern has risen about a global diabetes epidemic, with harmful effects on life expectancy and health-care costs.[8,9] A few studies have examined global patterns of glycaemia and diabetes, finding substantial variation between regions.[1,10–13] Others have assessed trends in specific countries.[14–24] Findings from these studies have helped to show that hyperglycaemia and diabetes are important worldwide and regional issues, but these studies also have limitations.

First, diabetes definitions have varied by expert committees and over time.[25–27] Most current studies have either used all definitions without adjustment for incomparability, or selected one definition and excluded data based on other definitions. Second, these studies pooled national, subnational, and community data, regarding them as equally representative of countries' populations. Third, some data included in these studies used random (non-fasting) glucose measurement; other data were from specific occupational groups, communities with high obesity prevalence, health-care facilities and practitioners, registries, or self-reported diabetes. These sources were probably biased because obesity is a risk factor for hyperglycaemia, occupational groups might differ from the general population in their

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See Online for webappendix

health risks, and some diabetes cases are undiagnosed.[28,29] Fourth, previous analyses assigned estimates to countries without data based on geographical proximity and ad-hoc expert opinion about similarity to countries with data without a formal analytical model. Fifth, these studies pooled data from different years without adjustment for underlying trends. Finally, these studies did not account for all sources of uncertainty including missing and older country data, leading to overly confident estimates.

These shortcomings have hindered our ability to systematically examine trends. In recent years, health examination surveys have measured different glycaemic indicators, providing an opportunity to systematically assess trends by country. We reviewed and accessed unpublished and published studies and collated comprehensive data for different glycaemic metrics. We applied statistical methods to systematically address measurement comparability, missing data, non-linear time trends, age patterns, and national versus subnational and community representativeness. With these data and methods, we estimated trends and associated uncertainties by country and region.

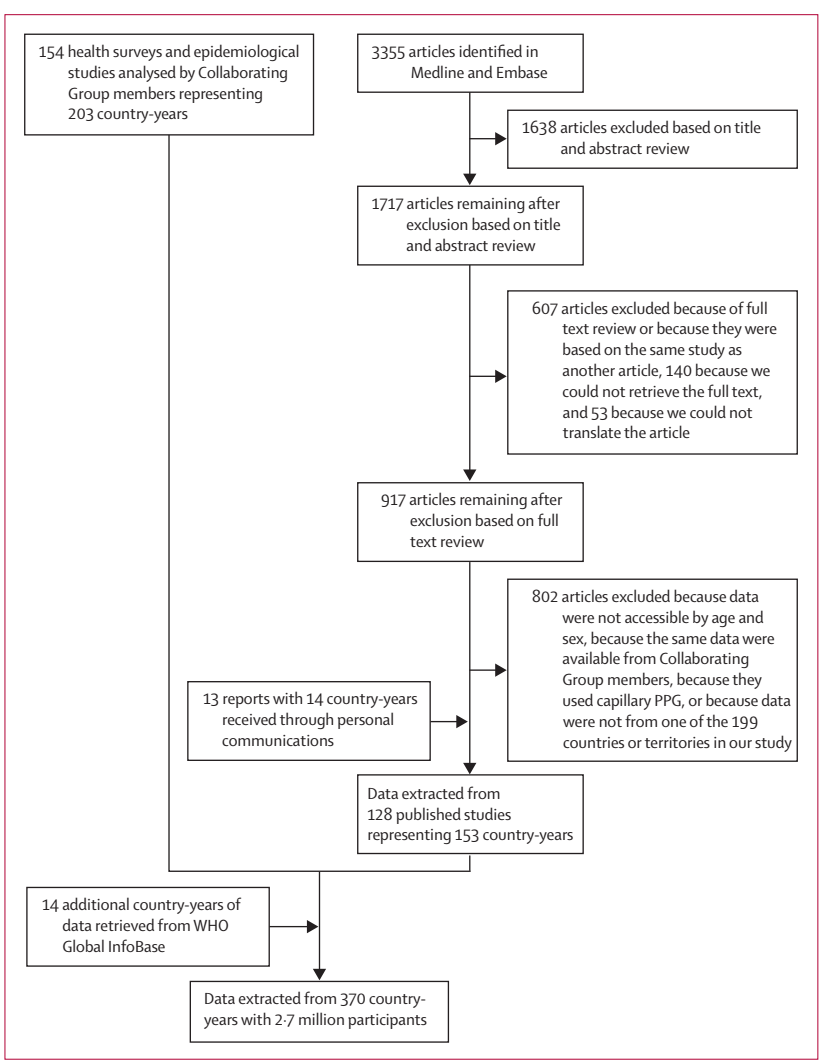

Figure 1: **Flow diagram for data source identification and access**
PPG=postprandial glucose.

Methods

Study design

We estimated 1980–2008 trends in mean fasting plasma glucose (FPG) and diabetes by sex, for 199 countries and territories in the 21 subregions of the Global Burden of Diseases, Injuries, and Risk Factors study, which themselves are grouped into larger regions (webappendix p 6).

We used mean FPG, rather than postprandial glucose or haemoglobin A_{1c} (HbA_{1c}), as the primary measure of glycaemia because it is used in many more population-based studies. We report population mean because there is a continuous association between FPG and cardiovascular disease, including at levels below clinical thresholds for diabetes diagnosis.[2,30,31] We report diabetes prevalence as a secondary outcome because it is clinically relevant and because associations with microvascular outcomes can have a threshold.[32–34] We used the American Diabetes Association (ADA) definition for diabetes: FPG 7·0 mmol/L or greater, diagnosis, or use of a glucose-lowering drug.[25] Estimates for primary and secondary outcomes were informed by all available data sources, with systematic conversion between glycaemic metrics and definitions.

Our analysis of primary measure (mean FPG) included three steps: (1) identification of data sources, and accessing and extracting of data; (2) conversion of data that were reported in other metrics to FPG; and (3) application of statistical models to estimate trends in mean FPG by country and sex. We analysed the uncertainty of estimates, taking into account sampling error and uncertainty from statistical modelling in steps 2 and 3.

Data sources

Our data sources were health examination surveys and epidemiological studies with data available to Collaborating Group members, multicentre studies, published articles, and unpublished data identified through the WHO Global InfoBase. Figure 1 and webappendix pp 2–3 provides details of data identification, access, and extraction. Duplicate sources were identified by comparison of all studies from the same country-year. Data that were based solely on known or self-reported diabetes were excluded because some cases might be undiagnosed and lead to underestimation of prevalence.[28,29]

Fasting and postprandial glucose in venous whole blood and fasting glucose in capillary whole blood were multiplied by 1·11 to convert to equivalent plasma glucose;[35] 19 studies with postprandial glucose in capillary whole blood were excluded because the relation with plasma glucose is highly variable.[36] For each data source,

we recorded whether the data were national (separated into weighted and unweighted), subnational (covered multiple communities, provinces, or states), or from individual communities (denoted study coverage hereafter); and whether the study population was rural, urban, or both (webappendix pp 7–24). This information was used to account for potential bias and additional variability in data sources that were not representative of their national populations.

Conversion between glycaemic metrics

Although mean FPG was the most common metric in our data, some sources reported mean postprandial glucose or HbA_{1c}. Further, some published studies reported diabetes prevalence, with varying definitions, but not mean glucose. We used data sources that had mean FPG and other metrics to develop regression models to estimate mean FPG. The dependent variable in these cross-walking regressions was mean FPG; the independent variables were mean postprandial glucose, mean HbA_{1c}, or diabetes prevalence, and age, sex, year of survey, and whether the country was high income. We developed a separate regression for each diabetes definition used in at least one published study. Webappendix pp 4 and 25–30 provides model details and coefficients.

We used a similar approach to estimate diabetes prevalence, our secondary outcome, from the estimated mean FPG. The dependent variable of this reverse cross-walking regression was the logit of prevalence (based on the ADA definition), and the independent variables were Ln of mean FPG, age, sex, as well as whether the country was high income. The uncertainties of the prevalence estimates included those of the estimated mean FPG and uncertainty associated with conversion of mean to prevalence. Details of uncertainty analyses are provided elsewhere.[37] Webappendix p 31 provides the coefficients of the regression.

Methods for country mean FPG estimates

Many country-years had no data or no nationally representative data. Further, some studies covered only some age groups. We developed a statistical model to estimate mean FPG, by age group, country, and year, separately for men and women. We used a Bayesian hierarchical model in which estimates for each age-country-year unit were informed by data from that unit itself, if available, and by data from other units. Specific model features are described briefly here, with complete details provided elsewhere.[37]

We used a hierarchical model in which mean FPG values and trends in countries were nested in subregional, regional, and global values and trends. The hierarchical model borrows information across countries, subregions, and regions, appropriately compromising between (overly) uncertain within-unit estimates and (overly) simplified aggregate cross-unit estimates; it borrows information to a greater degree when data are non-existent or non-informative (ie, have large uncertainty), and to a lesser degree in data-rich countries, subregions, and regions.

FPG trends over time were modelled as a linear trend plus a smooth non-linear trend, at all levels. Both components were modelled hierarchically. Time varying country-level covariates informed the estimates. The covariates, described in webappendix p 5 and elsewhere,[37] were national income (Ln per-head gross domestic product converted to international dollars in 1990), urbanisation (proportion of population that lived in urban areas), national availability of multiple food types, and age-standardised mean body-mass index (BMI).[7]

Subnational and community studies might systematically differ from nationally representative ones because they might be undertaken in low-glucose or high-glucose areas. They might also have larger variation than national studies. Our model included offsets for subnational and community data, and additional variance components for subnational and community data and for national data without sample weights. These variance components were estimated empirically and allowed national data with sample weights to have more effect on estimates than other sources.

Mean FPG might differ systematically between rural and urban populations, with the difference dependent on the country's level of urbanisation. Therefore, the model included an offset for rural-only and urban-only data. The offset was empirically estimated and was weighted by the difference between study-level and country-level urbanisation.

Mean FPG might be non-linearly associated with age, and the age association might flatten or decrease in older ages. The age association might vary across countries, and might be steeper when mean FPG is higher. Therefore, we used a cubic spline age model, with parameters estimated as a function of mean FPG at a baseline age.

Mean FPG was estimated from the model for 5–10-year age groups for adults aged 25 years and older. Estimates for subregions, regions, and the world were calculated as population-weighted averages of the constituent country estimates by age group and sex. For presentation, estimates for each country or region and year were age-standardised to the WHO reference population.[38]

We quantified the following sources of uncertainty, with details provided elsewhere:[37] sampling uncertainty in the original data sources; uncertainty associated with fluctuations over time in national data, because of unmeasured study design factors (eg, national data from the USA in webappendix pp 218 and 350) or because some surveys did not have sample weights; additional uncertainty associated with data sources that were not national, because of variation across communities in each country; uncertainty associated with conversion of various glycaemic metrics to FPG (primary outcome) and between mean FPG and diabetes prevalence (secondary outcome); and uncertainty due

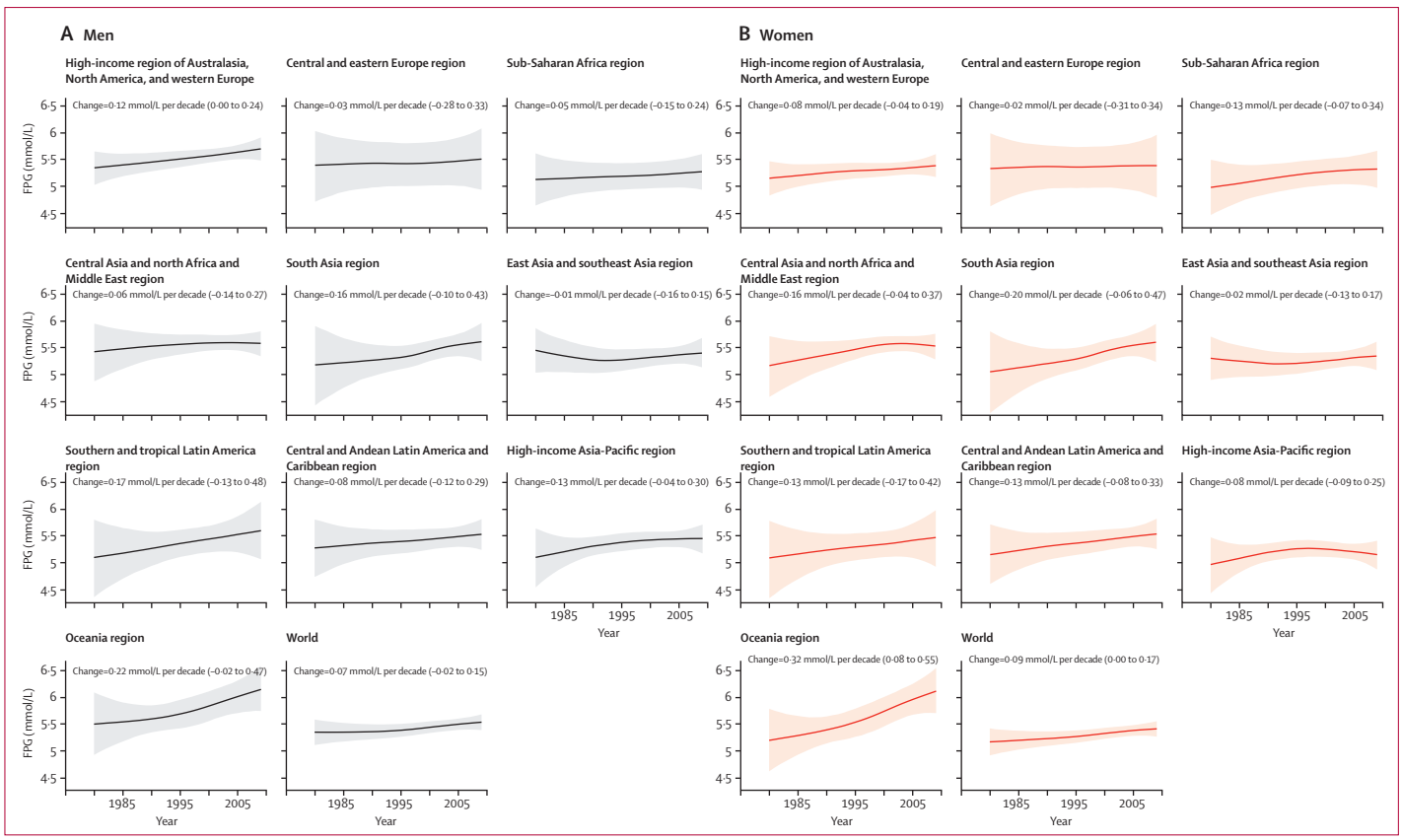

Figure 2: **Trends in age-standardised mean FPG by region between 1980 and 2008 for men (A) and women (B)**
Webappendix pp 51–53 shows trends by subregion and webappendix pp 57–91 trends by country. The solid line represents the posterior mean and the shaded area the uncertainty interval. FPG=fasting plasma glucose.

to making estimates by age group, country, and year when data were missing.

As described in detail elsewhere,[37] we fitted the Bayesian model with the Markov chain Monte Carlo (MCMC) algorithm and obtained samples from the posterior distribution of model parameters, which were in turn used to obtain the posterior distribution of mean FPG. The uncertainty intervals reported represent the 2·5–97·5 percentiles of the posterior distribution of estimated means. Change was estimated as linear trend over the 29 years of analysis and is reported as change per decade. We also report the posterior probability that an estimated increase or decrease represents a truly increasing or decreasing trend as opposed to a chance observation.

We report estimates for all country-years, many of which were without data. We verified the external predictive validity of these (out-of-sample) estimates and their uncertainty intervals. We divided the countries with data into five non-overlapping groups of equal size such that each group contained a mix of countries with rich data (≥4 years of data), average density data (2–3 years of data), and poor data (1 year of data). Within each group of countries, we withheld 10% of data sources. For a specific country, we withheld either all the country's data (ie, created the appearance of countries with no data when we actually had data), or all the country's 2000–09 data (ie, created the appearance of no recent data), or a random third of the country's data. Our goals were to measure how well we estimated FPG for countries without data, how well we estimated recent FPG for countries without recent data, and how well we filled in the gaps for countries with intermittent data. For each of the five groups, we fitted the model to the remaining 90% of the dataset and made estimates of the withheld observations. We then examined whether the estimated 95% uncertainty intervals around these estimates covered the withheld study means. In a model with good external predictive validity, 95% of withheld values would be covered by the uncertainty intervals. We assessed external predictive validity for the full withheld dataset and for subsets based on region, age, gross domestic product and urbanisation level, and year of data.

Role of the funding source

The sponsor of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The Writing and Global Analysis

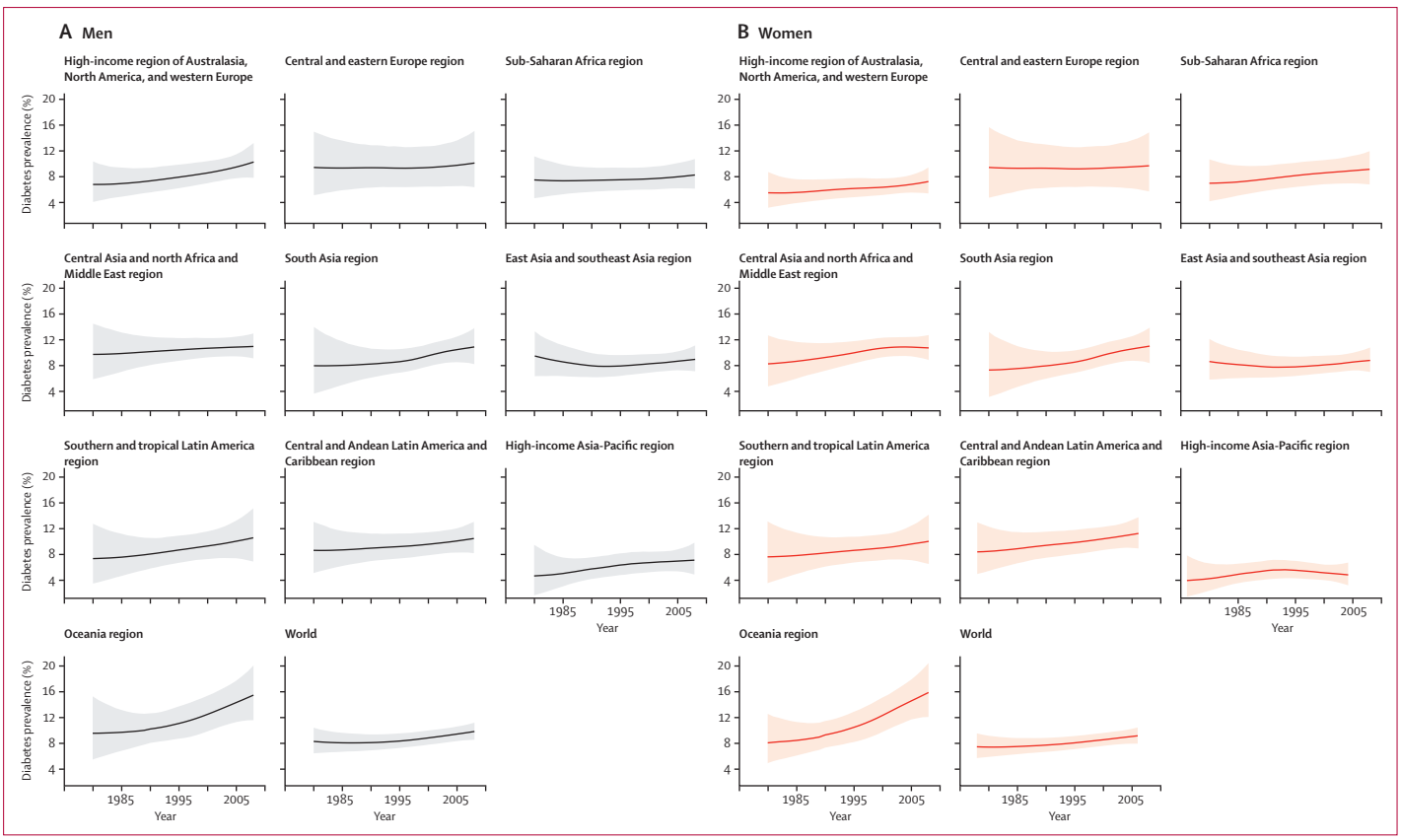

Figure 3: **Trends in age-standardised diabetes prevalence by region between 1980 and 2008 for men (A) and women (B)**
Webappendix pp 54–56 shows trends by subregion.

Group had access to all data sources and has responsibility for the decision to submit for publication.

Results

Our final dataset included 370 country-years with 2·7 million participants (figure 1). Of the included studies, 71% had reported mean FPG or diabetes prevalence based on FPG, with others using postprandial glucose or HbA_{1c} (webappendix pp 7–24). 128 country-years were from 22 high-income countries and 242 from 85 low-income and middle-income countries. Japan had the most nationally representative data with 8 years of national data since 1980, followed by the USA and Singapore (webappendix pp 46–48). We could not identify any population-based data for 92 countries. Central Asia, central and eastern Europe, and sub-Saharan Africa had the largest proportion of countries without data (webappendix pp 49–50). National surveys contributed 29% of all data, subnational studies 19%, and community studies 52% (webappendix pp 49–50).

Globally, age-standardised mean FPG was 5·50 mmol/L (95% uncertainty interval 5·37–5·63) for adult men and 5·42 mmol/L (5·29–5·54) for women in 2008 (figure 2), having risen by an estimated 0·07 mmol/L per decade (–0·02 to 0·15; posterior probability of the observed increase being a true increase=0·94) for men and 0·09 mmol/L per decade (0·00–0·17; posterior probability=0·98) for women since 1980. Age-standardised prevalence of diabetes was 9·8% (8·6–11·2) in men and 9·2% (8·0–10·5) in women in 2008 (figure 3), leading to an estimated 173 (151–197) million men and 173 (151–197) million women with diabetes. 40% (about 138 million) of people with diabetes were from China and India, 10% (about 36 million) from the USA and Russia, and 12% (about 42 million) from Brazil, Pakistan, Indonesia, Japan, and Mexico. In 1980, age-standardised prevalence was 8·3% (6·5–10·4) in adult men and 7·5% (5·8–9·6) in women, yielding 77 (60–97) million men and 76 (58–97) million women with diabetes. Of the nearly 194 million additional cases of diabetes between 1980 and 2008, 70% (52–98) were attributable to population growth and ageing and the other 30% (2–48) to a rise in age-specific prevalences. Across regions, the epidemiological share of the change ranged from –2% in east and southeast Asia to 60% in Oceania (data not shown).

In 2008, mean FPG in men was lowest in sub-Saharan Africa (5·27 mmol/L, 4·96–5·58), followed by east and southeast Asia and high-income Asia-Pacific (figure 2). Women in high-income Asia-Pacific had the lowest mean

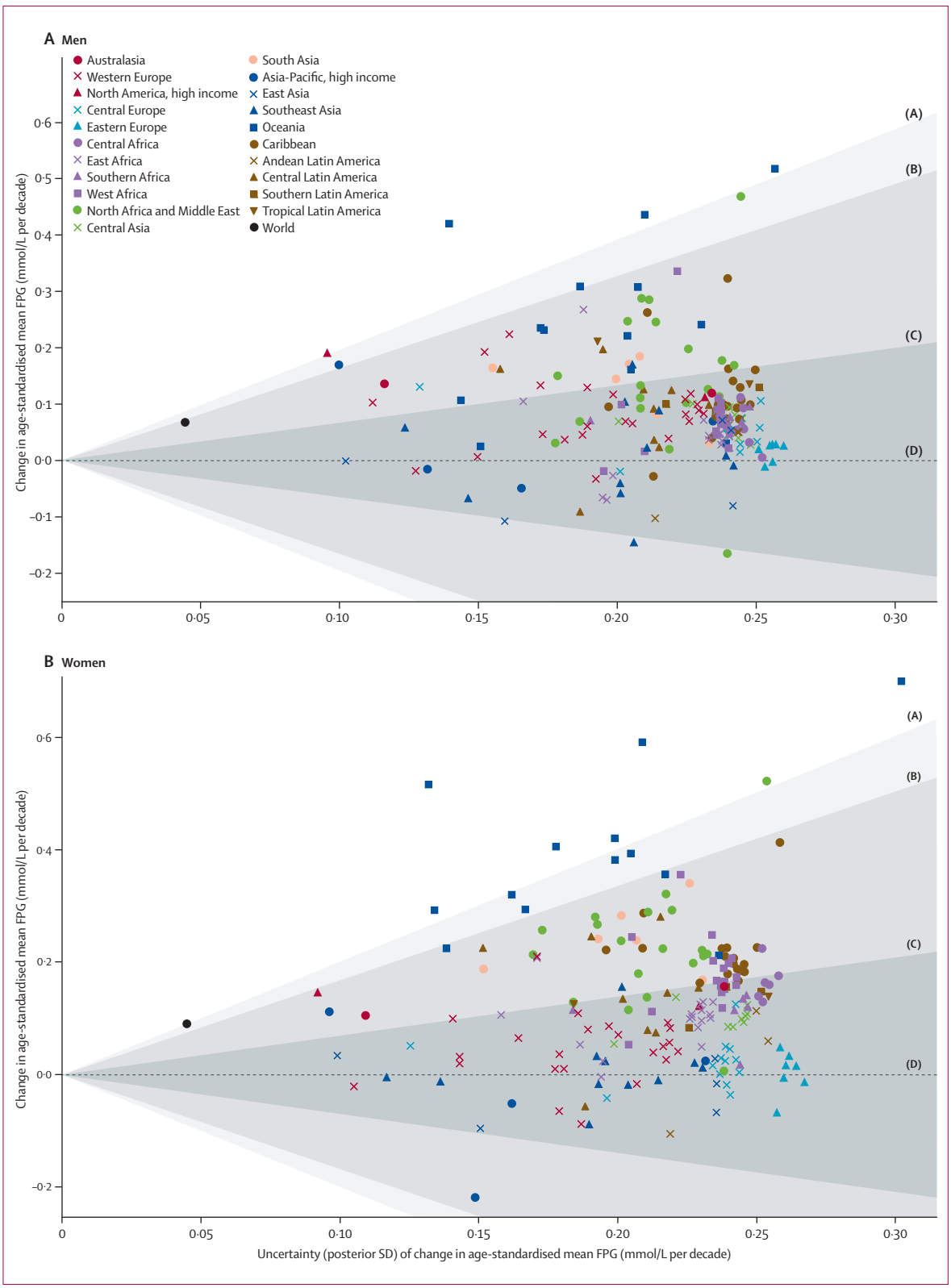

Figure 4: **Change in country age-standardised mean FPG between 1980 and 2008 in relation to its uncertainty for men (A) and women (B)**
The shaded areas roughly represent the following ranges of posterior probability (PP) of an estimated increase or decrease being a true increase or decrease: PP>0·975 (A); 0·95<PP<0·975 (B); 0·75<PP<0·95 (C); and PP<0·75. FPG=fasting plasma glucose.

FPG (5·17 mmol/L; 4·94–5·39) followed by sub-Saharan Africa and east and southeast Asia (figure 2). Oceania had the highest mean FPG and diabetes prevalence of any region in 2008, for both men (6·09 mmol/L, 5·73–6·49; and 15·5%, 11·6–20·1) and for women (6·08 mmol/L, 5·72–6·46; and 15·9%, 12·1–20·5). Mean FPG and diabetes prevalence were also high for both sexes in south Asia, Latin America and the Caribbean, and a region consisting of central Asia, north Africa, and the Middle East (figure 2 and figure 3). Men in the high-income region consisting of Australasia, North America, and western Europe also had relatively high FPG and diabetes prevalence (figure 2 and figure 3). In high-income subregions, mean FPG and diabetes were lower in Asia-Pacific and western Europe than in Australasia and north America, with the difference between the highest and lowest means and prevalences about 0·4 mmol/L and 4–5 percentage points, respectively (webappendix pp 51–56).

With few exceptions, countries with the highest FPG and diabetes prevalence in 2008 were in Oceania, north Africa and the Middle East, and the Caribbean, with age-standardised mean FPG 6·5 mmol/L or higher in the Marshall Islands, Kiribati, Saudi Arabia, the Cook Islands, and Samoa in both sexes (figure appendix 1); age-standardised diabetes prevalence in these countries ranged 21–25% in men and 21–32% in women (figure appendix 2). Countries in southeast Asia, east Africa, and Andean Latin America had the lowest mean FPG in 2008 (as low as 5 mmol/L or less; figure appendix 1). Of high-income countries, mean FPG and diabetes were highest in the USA, Greenland, Malta, New Zealand, and Spain, and lowest in the Netherlands and Austria, for both sexes and in France for women (figure appendix 1). Mean FPG in these western European countries was lower than in Japan and South Korea, despite having higher BMIs.[7]

FPG increased or at best remained unchanged in almost every region between 1980 and 2008 (figure 2). FPG increased the most in Oceania, by 0·22 mmol/L per decade (–0·02 to 0·47; posterior probability=0·97) in men and 0·32 mmol/L per decade (0·08–0·55; posterior probability >0·99) in women. This rise led to an estimated increase in age-standardised diabetes prevalence of 5·9 percentage points for men and 7·8 percentage points for women in this region (figure 3). Large increases in mean FPG were also recorded in southern and tropical Latin America and south Asia for men, and in south Asia and the combined region of central Asia, north Africa, and the Middle East for women (all >0·15 mmol/L per decade; posterior probabilities ≥0·87). In men and women, we recorded almost no change in mean FPG in east and southeast Asia and in central and eastern Europe during these 28 years (figure 2). Male FPG trend in sub-Saharan Africa was indistinguishable from no change (posterior probability=0·69), but women had an increase of 0·13 mmol/L per decade (–0·07 to 0·34; posterior probability=0·91). In high-income subregions, FPG increased the least in western Europe, by 0·07 mmol/L per decade (–0·08 to 0·21; posterior probability=0·82) in men and by 0·03 mmol/L per decade (–0·13 to 0·18; posterior probability=0·63) in women, which was statistically indistinguishable from no change. Conversely, in high-income North America, FPG rose by 0·18 mmol/L per decade (0·00–0·36; posterior probability=0·98) in men and 0·14 mmol/L per decade (–0·03 to 0·31; posterior probability=0·94) in women.

Apart from women in Singapore, for whom mean FPG decreased by 0·21 mmol/L per decade (–0·06 to 0·51; posterior probability=0·92), no country had a meaningful fall in FPG; the few countries with apparent decreases had posterior probabilities of 0·80 or less and hence were statistically indistinguishable from flat trends (figure 4). Countries with flat trends were in east and southeast Asia, sub-Saharan Africa, Andean and central Latin America, high-income Asia-Pacific, and, especially for women, in Europe (figure 4). Countries in Oceania and North Africa and the Middle East had the largest increase in mean FPG, by 0·5 mmol/L per decade or more in the Marshall Islands, Samoa, Kiribati, and Saudi Arabia.

Our model did well in external predictive validity tests. Specifically, the 95% uncertainty intervals of our model predictions included 95% of withheld study means for women and 96% for men (webappendix p 45). Our model also had good predictive validity in most regions and by year of data, gross domestic product, and age group. When we excluded all data for some countries (ie, created the appearance of no data when data were available), the uncertainty intervals of model predictions included 96% of the female study means that were known but excluded, and 98% of the male study means. Although data were sparse early in our analysis period, our model covered 99% of withheld values from 1980 to 1995, suggesting that our uncertainty estimates were slightly conservative when data were scarce.

Discussion

Our systematic analysis shows that glycaemia and diabetes are a rising global hazard, with the number of adults with diabetes having more than doubled over nearly three decades. Although population growth and ageing are important contributors to this increase, there is also an important epidemiological component with age-standardised global mean FPG having increased by 0·07 mmol/L per decade or more.

Our estimate of 347 (314–382) million adults with diabetes is higher than Shaw and colleagues' estimate of 285 million for 2010 (panel).[13] The differences between the estimates could be explained by the inclusion and exclusion criteria and the number of studies used, different age ranges of estimates, or different methods to deal with missing data, year of data, rural and urban data, and national versus subnational and community data. Recent narrative reviews have stated that diabetes is rising in Asia and Africa, without addressing whether

Panel: Research in context

Systematic review

A few studies have examined global patterns of glycaemia and diabetes, but have not estimated past trends for all countries and regions. Other studies have assessed trends in specific countries or regions. A recent publication estimated that there were 285 million people with diabetes worldwide in 2010,[13] but some of the data were from specific occupational groups, communities with high obesity prevalence, or health-care facilities and practitioners, registries, and self-reported diabetes. Recent narrative reviews[20,39–41] have stated that diabetes is rising in Asia and Africa, without addressing incomparable age groups in the studies included and other aspects of data comparability. Previous studies (including one by some members of our study group[1]) also had not distinguished between data that are nationally representative and those that are subnational or from specific communities. We obtained data for the levels of different glycaemic metrics from the following sources: health examination surveys and epidemiological studies with anonymised data available to the Collaborating Group members; multicentre studies; review of published articles; and unpublished data sources identified through the WHO Global InfoBase. Our final dataset included 370 country-years with 2·7 million participants. We could not identify any population-based data for 92 countries. We had data for mean fasting and postprandial glucose, mean HbA_{1c}, and diabetes prevalence with use of 18 different definitions. We systematically converted between different glycaemic metrics based on data sources that had measured multiple metrics.

Interpretation

Our estimate of 347 (uncertainty interval 314–382) million adults with diabetes in 2008, is higher than the previous 285 million estimate for 2010.[13] The differences between the estimates could be due to the inclusion and exclusion criteria and the number of studies used; different age ranges of estimates; or different methods of handling missing data, differences in year of data, rural and urban data, and national versus subnational and community data. Although we generally found increasing mean fasting plasma glucose and diabetes prevalence, our quantitative results are not comparable with the previous reports because we had used a larger number of studies and different methods. Notably, with use of national studies from China, Taiwan, Thailand, Malaysia, Cambodia, and the Philippines, and multiple subnational and community studies, we recorded no increase in age-standardised diabetes prevalence in east and southeast Asia, although ageing and population growth led to an increase in the number of people with diabetes in these regions.

the data were representative, whether age groups were the same in the included studies, and other aspects of data comparability.[20,39–41] We screened all data sources used in these overviews and used additional sources. Although we generally recorded increasing mean FPG and diabetes prevalence, our quantitative results are not comparable with the previous reports because we had used a larger number of studies and different methods. Notably, with use of national studies from China, Taiwan, Thailand, Malaysia, Cambodia, and the Philippines, in addition to multiple subnational and community studies, we noted no increase in age-standardised diabetes prevalence in east and southeast Asia, although ageing and population growth led to an increase in the number of people with diabetes.

The strengths and innovations of this study include analysis of trends; the large amount of data accessed and used; systematic conversion between different metrics of glycaemia and definitions of diabetes; application of a Bayesian hierarchical model to estimate mean FPG, which included non-linear time trends and age associations and used national income, urbanisation, food availability, and BMI as covariates; incorporation of study coverage as offset and variance components; and systematic analysis and reporting of uncertainty. Coverage-specific offsets and variances allowed our estimates to use all available data and to follow data from nationally representative studies more closely. Coverage-specific variance components were larger for less representative data sources, which led to larger uncertainty when we did not have nationally representative data, thus representing the true availability of information.

The main limitation of our study is that despite extensive data seeking, many country-years still did not have data, especially in the 1980s and in some low-income and middle-income countries. The absence of data is reflected in wider uncertainty intervals. Our external predictive validity assessment showed that the estimates and their uncertainty intervals are valid; importantly, applications of our results should use the full uncertainty intervals. Further, we noted substantial incomparability in metrics of glycaemia in published data. Specifically, we had data for mean postprandial glucose, mean HbA_{1c}, and diabetes prevalence using 18 different definitions. Although we systematically converted between different glycaemia metrics, the conversions led to increases in uncertainty intervals. Similarly, to estimate diabetes prevalence, we relied on mean FPG as an intermediate step for conversion between different metrics and for handling of missing data. The association between mean and prevalence could vary between countries beyond what is measured by variables in webappendix p 31—eg, because of variations in quality of care. Such variability is shown by larger uncertainty in our prevalence estimates than the uncertainty of mean FPG. The persistent incomparability of glycaemic metrics is partly because definitions for clinical purposes are the subject of continuous debate, research, and refinement. Population-based surveillance, however, needs indicators that are easy to measure and are comparable across populations and over time. Although we incorporated information about study coverage into our model and excluded studies based on random (non-fasting) blood glucose, other quality indicators—such as duration of fasting, laboratory methods, calibration, and other sources of interassay and intra-assay variability—were not included in the model, potentially accounting for some of the uncertainty in our estimates.

As important as the global rise were the similarities and differences between regions and countries. Trends ranged from nearly flat in some regions to a rise of 0·2–0·3 mmol/L per decade in Oceania. This variation is undoubtedly partly attributable to regional BMI trends;[7] the correlation between change in BMI and FPG across the 21 subregions was 0·71 for women and 0·57 for men.

However, genetic factors associated with ethnic origin, fetal and early life nutritional status, diet quality, and physical activity might also affect glycaemic values and trends. Notably, men in south Asia had the second smallest change in BMI (almost zero) of the 21 subregions[7] but the sixth highest rise in mean FPG; women in this region had the fourth smallest BMI change (0·4 kg/m² per decade) but the sixth largest rise in FPG, about the same as in high-income North America where female BMI rose three times as much.[7]

The global and regional trends in mean FPG differ from those of other metabolic risks—namely, systolic blood pressure which decreased globally and in most subregions,[37] and total cholesterol which decreased in Australasia, Europe, and North America, but rose in east and southeast Asia and Asia-Pacific, leading to relatively unchanged global mean.[42] Because high BMI is a risk factor for all three metabolic indicators, these differences probably arise from other determinants, including dietary composition and medical treatment. Specifically, although effective drugs to lower blood pressure and cholesterol are increasingly used for primary prevention of cardiovascular disease in high-income countries, the use of specific drugs for primary prevention, and the targets and intensity of glycaemic management, are still being investigated.[43] Therefore, primary prevention of dysglycaemia will need weight control, physical activity, and improved diet quality. Such interventions are difficult to implement within populations and will not affect diabetes incidence in the short term. Therefore, health systems in most countries will inevitably have to develop programmes to improve detection and management of diabetes to slow progression to microvascular and macrovascular complications.

Contributors

GD and ME developed the study concept. GD, YL, MR, and CAR undertook reviews of published studies and managed databases. JKL, MJC, GMS, YL, Y-HK, and members of Country Data Group analysed health examination survey and epidemiological study data. MMF and CJP developed the Bayesian statistical model with input from GD and ME. MMF, YL, GMS, JKL, and GD analysed databases and prepared results. GD and ME wrote the first draft of the report. Other members of the Writing and Global Analysis Group contributed to study design, analysis, and writing of report. ME, GD, and CJP oversaw the research. ME is the study guarantor for this report.

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Conflicts of interest

CJP holds stock in Pfizer. JKL holds stock in Johnson & Johnson. ME has chaired a session at the World Cardiology Congress, which was supported by the organiser. All other authors declare that they have no conflicts of interest.

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