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ABSTRACT

OBJECTIVE
To estimate the global burden of type 2 diabetes in adolescents and young adults (aged 15-39 years) from 1990 to 2019.

DESIGN
Systematic analysis.

DATA SOURCE

MAIN OUTCOMES MEASURES
Age standardised incidence rate, age standardised disability adjusted life years (DALY) rate, and age standardised mortality rate for type 2 diabetes in people aged 15-39 years from 1990 to 2019, and proportional DALY attributable to different risk factors.

RESULTS
From 1990 to 2019, significant increases in age standardised incidence rate and age standardised DALY rate were found for type 2 diabetes in adolescents and young adults globally (P<0.001). Age standardised incidence rate (per 100,000 population) increased from 117.22 (95% confidence interval 117.07 to 117.36) in 1990 to 183.36 (183.21 to 183.51) in 2019, and age standardised DALY rate (per 100,000 population) increased from 106.34 (106.20 to 106.48) in 1990 to 149.61 (149.47 to 149.75) in 2019. The age standardised mortality rate (per 100,000 population) was modestly increased from 0.74 (0.72 to 0.75) in 1990 to 0.77 (0.76 to 0.78) in 2019. When grouped by countries with different sociodemographic indexes, countries with a low-middle and middle sociodemographic index had the highest age standardised incidence rate and age standardised DALY rate in 2019, whereas countries with a low sociodemographic index had the lowest age standardised incidence rate but the highest age standardised mortality rate. Women generally had higher mortality and DALY rates than men at ages <30 years, but differences between the sexes were reversed in those aged >30 years except in countries with a low sociodemographic index. The main attributable risk factor for DALY for early onset type 2 diabetes was high body mass index in all regions by sociodemographic index. The proportional contribution of other risk factors varied across regions, however, with higher proportions of ambient particulate air pollution and smoking in countries with a high sociodemographic index and higher proportions of household air pollution from solid fuels and diet low in fruit in countries with a low sociodemographic index.

CONCLUSIONS
Early onset type 2 diabetes is a growing global health problem in adolescents and young adults, especially in countries with a low-middle and middle sociodemographic index. A greater disease burden in women aged <30 years was found. Specific measures are needed in countries with different levels of socioeconomic development because of the variable attributable risk factors for type 2 diabetes in adolescents and young adults.

WHAT IS ALREADY KNOWN ON THIS Topic

Studies in high income countries have suggested that the incidence and prevalence of type 2 diabetes in children and adolescents had substantially increased

The global disease burden and secular trend of early onset type 2 diabetes, and the variations in men and women in different socioeconomic categories, have not been described

The pattern of attributable risk factors for early onset type 2 diabetes in different countries has not been investigated

WHAT THIS STUDY ADDS

Since 1990, the age standardised incidence rate and age standardised DALY rate for the burden of early onset type 2 diabetes in adolescents and young adults (aged 15-39 years) have substantially increased globally

Countries with a low-middle and middle sociodemographic index and women aged <30 years were particularly affected

Weight control is essential in reducing the burden of early onset type 2 diabetes, but countries should establish specific policies to deal with this problem more effectively
progress of the pathological process (including severe insulin resistance and worsening β cell function), which then leads to worse glycaemic control and an increased risk of complications of diabetes. The Treatment Options for Type 2 Diabetes in Adolescents and Youth (TODAY) study, which included 699 participants aged 10-17 years with type 2 diabetes, reported that 60.1% of participants developed at least one microvascular complication and 28.4% developed at least two complications, within an average follow-up of 13.3 years. Early onset type 2 diabetes (eg, diagnosis before the age of 40 years) was also associated with substantially increased risks of cardiovascular disease and mortality compared with late onset diabetes. Also, treatment options for type 2 diabetes in children and adolescents are inadequate and less effective than treatment for adults. The TODAY study found that the an intensive lifestyle intervention (family based changes in eating and activity behaviours) in combination with metformin was not superior to metformin alone. Therefore, understanding the global disease burden of early onset type 2 diabetes is important for the provision of adequate healthcare resources in different regions.

Studies have reported on the global burden and trend in diabetes from 1990 to 2017 and on mortality from diabetes and trends before the age of 25 years, 1990-2019. No study has specifically described the global burden of disease and secular trend of early onset type 2 diabetes, however, and the variations between the sexes and in countries with different levels of socioeconomic development. Also, attributable risk factors for early onset type 2 diabetes in different countries are unclear, which might limit the establishment of effective measures to deal with the problem at the global, regional, and national levels.

Therefore, in this study, our aim was to provide more information on these issues by analysing data from the Global Burden of Diseases Study 2019 (Injuries and Risk Factors Collaborators). We describe the global epidemiological characteristics of early onset type 2 diabetes (ie, type 2 diabetes in adolescents and young adults aged 15-39 years) and show the secular trends and variations by several factors (age, sex, and region, categorised by sociodemographic index). We have also characterised attributable risk factors for early onset type 2 diabetes.

**Methods**

**Data source**

The Global Burden of Disease 2019 project estimated the incidence, mortality, and disability adjusted life years (DALY) associated with 369 diseases and injuries for 204 countries and territories from 1990 to 2019. Data were collected through systematic assessment of censuses, household surveys, civil registration and vital statistics, disease registries, notifications of disease, use of health services, air pollution monitors, satellite imaging, and other sources. Details of the Global Burden of Disease Study 2019 have previously been published. Because the Global Burden of Disease Study 2019 had data on type 2 diabetes only for people aged ≥15 years, our study focused on type 2 diabetes with an onset age of 15-39 years (defined as early onset type 2 diabetes). We obtained data on the incidence, DALY, and mortality of early onset type 2 diabetes specific to age, sex, and region, and DALY attributable to different risk factors (with corresponding 95% uncertainty intervals) from the Global Health Data Exchange (https://ghdx.healthdata.org/gbd-results-tool).

**Estimation of disease burden of type 2 diabetes in Global Burden of Disease Study 2019**

In the Global Burden of Disease Study 2019, diabetes was defined as a fasting plasma concentration of glucose of ≥126 mg/dL (7 mmol/L) or a report of treatment for diabetes. Data sources obtained through systematic review of the published literature, survey data, longitudinal studies, and other means were added to DisMod MR-2.1, a Bayesian meta-regression model, to estimate the non-fatal burden of diabetes overall and different types of diabetes. In the Global Burden of Disease dataset, only 20% of sources had information on the type of diabetes. Because of the inconsistent diagnostic criteria for type 2 diabetes across studies, the non-fatal burden of type 2 diabetes was estimated indirectly by subtracting the estimation of type 1 diabetes (patients who received a diagnosis from a doctor and were identified through a diabetic registry or hospital record) from that of all types of diabetes.

Mortality from type 2 diabetes was estimated by collecting deaths recorded from vital registration sources with ICD-10 (international classification of diseases, 10th revision) codes. A regression model was developed to estimate the proportion of type 2 diabetes among unspecified patients with diabetes. Finally, specified deaths and deaths estimated by regression analysis were inputted to the Cause of Death Ensemble model (CODEm) to estimate mortality from type 2 diabetes after adjusting for several selected covariates (details in supplementary materials).

The crude years lived with disability for type 2 diabetes were estimated from the prevalence multiplied by the disability weights for the health state (type 2 diabetes). A micro-simulation was applied to get the final estimation of years lived with disability after correction for comorbidity. Years of life lost were computed by multiplying the number of estimated deaths from type 2 diabetes by the standard life expectancy at age of death. DALY were equal to the sum of years lived with disability and years of life lost. The supplementary materials and other published literature give details of the estimation methods.

**Estimation of attributable risk factors for type 2 diabetes in Global Burden of Disease Study 2019**

The Global Burden of Disease Study 2019 estimated the attributable disease burden of 87 risk factors and combinations of risk factors at the global, regional, and
Attributable DALY is the reduction in current disease DALY that would have been possible if exposure to the risk factor at the population level had shifted to an alternative or counterfactual distribution of risk. Attributable DALY was estimated by multiplying the total DALY of a specific outcome by the population attributable fraction, which represents the proportion of outcomes that would decrease in a given population and time if exposed to a counterfactual level of the theoretical minimum risk exposure level. The supplementary materials and other published literature\(^{14}\) provide details of the definition of risk factors and specific estimation method in the Global Burden of Disease Study 2019.

### Statistical analysis

We calculated age standardised rates and corresponding 95% confidence intervals by standardisation, based on the world standard population reported in the Global Burden of Disease Study 2019.\(^{15}\) Rates in our estimates are shown per 100000 population.

To assess the magnitude and direction of temporal trends in the incidence, DALY, and mortality for early onset type 2 diabetes, we calculated average annual per cent change and corresponding 95% confidence intervals by joinpoint regression.\(^{16}\) The Joinpoint Regression Program software (version 4.9.0.0, National Cancer Institute, USA) took trend data and fitted the simplest joinpoint model allowed by the data. The programme started with the minimum number of joinpoints (eg, a straight line of 0 joinpoint) and tested whether more joinpoints were significant and should be added to the model. We used a Monte Carlo permutation method for tests of significance. The average annual per cent change was calculated from the annual per cent change of each segment in the last significant model in a weighted manner.

We conducted comparisons between the sexes, age groups (five year intervals; 15-19, 20-24, 25-29, 30-34, and 35-39 years), and sociodemographic index (five categories). The supplementary materials provide details about sociodemographic index. Least squares regression and generalised additive models were applied to examine the possible linear or non-linear relations between sociodemographic index and age standardised rates or corresponding average annual per cent change.

The proportional contribution of each risk factor was estimated by dividing the attributable DALY for that factor by the total DALY for early onset type 2 diabetes. Because the protective effect of moderate consumption of alcohol on type 2 diabetes is debated,\(^ {17}\) and the population attributable fraction by high fasting plasma glucose level was assumed to be 100% in the Global Burden of Disease Study 2019,\(^ {14}\) we did not include consumption of alcohol and high fasting plasma glucose level in our final analysis. R software (version 4.1.0) was used for the statistical analyses. A P value <0.05 was regarded as significant.

### Patient and public involvement

The Global Burden of Disease Study is a global collaborative scientific effort involving more than 7500 people from about 150 countries. We did not consider involving patients when designing the study because we used the secondary data from the Global Burden of Disease Study 2019, and the research question was not directly relevant to diabetes management for patients. No patients were involved in setting the specific research question, collecting and analysing the data, interpreting the results, or writing up the manuscript.

### Results

#### Global distribution of early onset type 2 diabetes in 2019

In 2019, the global age standardised incidence rate, age standardised DALY rate, and age standardised mortality rate per 100000 population were 183.36 (95% confidence interval 183.21 to 183.51), 149.61 (149.47 to 149.75), and 0.77 (0.76 to 0.78), respectively. By sociodemographic index category, we found the highest age standardised incidence rate and age standardised DALY rate in countries with a low-middle sociodemographic index (age standardised incidence rate 201.17, 95% confidence interval 200.84 to 201.50; age standardised DALY rate 174.20, 173.89 to 174.51), and countries with a low sociodemographic index had the lowest age standardised incidence rate (151.20, 150.82 to 151.58) but the highest age standardised mortality rate (1.03, 1.00 to 1.07) (fig 1 and table S1). The association between age standardised incidence rate, age standardised DALY rate, and age standardised mortality rate with sociodemographic index showed an inverse U shaped curve, with a higher age standardised incidence rate and age standardised DALY rate in countries with a low-middle and middle sociodemographic index and higher age standardised mortality rate in countries with a low sociodemographic index (all models, P<0.001) (fig S1). At the regional level, the greatest burden of early onset type 2 diabetes was seen in parts of Oceania and South Asia (figs S2-S4 and table S1); at the national level, the 10 countries with the highest age standardised incidence rate, age standardised DALY rate, and age standardised mortality rate in 2019 were all from Oceania (eg, Marshall Islands and Solomon Islands), making it the region with the greatest burden of early onset type 2 diabetes.

The age standardised incidence rate and age standardised DALY rate were higher in men (205.53 and 159.96) than in women (160.82 and 139.15) globally, whereas the age standardised mortality rate was similar for men and women (fig 1 and table S1). Age specific incidence, DALY, and mortality rates all increased with age (fig S5 and table S2).

Examination of age distribution showed that the differences in incidence, DALY, and mortality between men and women were mainly attributable to differences in the older age groups (30-34 and 35-39 years) (fig S5a-c). Among those aged <30 years, women had higher DALY and mortality than men with few exceptions, but the difference lessened with age.

The proportional contribution of each risk factor by high fasting plasma glucose level was assumed to be 100% in the Global Burden of Disease Study 2019,\(^ {14}\) we did not include consumption of alcohol and high fasting plasma glucose level in our final analysis. R software (version 4.1.0) was used for the statistical analyses. A P value <0.05 was regarded as significant.
increase in sociodemographic index. Furthermore, at ages >30 years, differences between the sexes in DALY and mortality were reversed, except in countries with a low sociodemographic index (fig 2, fig 3, fig 4, and table S2).

**Temporal trend of early onset type 2 diabetes from 1990 to 2019**

Figure 1 and table S1 show that the age standardised incidence rate and age standardised DALY rate for both sexes increased from 1990 to 2019 globally and
The age standardised incidence rate increased from 117.22 (95% confidence interval 117.07 to 117.36) in 1990 to 183.36 (183.21 to 183.51) in 2019 globally. Compared with countries with a low sociodemographic index, the age standardised incidence rate in countries with a high sociodemographic index increased faster, with an average annual per cent change of 1.38% (95% confidence interval 1.34% to 1.42%) and 1.99% (1.87% to 2.12%), respectively. The age standardised DALY rate increased from 106.34 (95% confidence interval 106.20 to 106.48) in 1990 to 149.61 (149.47 to 149.75) in 2019 globally. Compared with countries with a low sociodemographic index, the age standardised DALY rate in countries with a high sociodemographic index increased faster, with an average annual per cent change of 0.70 (95% confidence interval 0.65 to 0.76) and 2.01 (1.95 to 2.06), respectively.

When classified by different regions, western Europe and southern Latin America had the fastest increases in the age standardised incidence rate and age standardised DALY rate for early onset type 2 diabetes between 1990 and 2019. At the country level, the UK and Canada had the fastest increase in the age standardised incidence rate and age standardised DALY rate, respectively (figs S2-S4 and table S3). The average annual per cent increases in age standardised incidence rate and age standardised DALY rate were faster in men, except in countries with a high sociodemographic index (fig 1 and table S1). Generally, younger age was associated with greater increases in the incidence rate and DALY rate in countries with a high sociodemographic index (fig S5d-e and table S2).

We found fluctuations in changes in the age standardised mortality rate at the global level from 1990 to 2019, and the overall changes were modest. The age standardised mortality rate increased slightly but significantly from 0.74 (95% confidence interval 0.72 to 0.75) in 1990 to 0.77 (0.76 to 0.78) in 2019 (P<0.001). The age standardised mortality rate in countries with a high, high-middle, and low sociodemographic index showed a declining trend but was unchanged in countries with a middle sociodemographic index or even increased in countries with a low-middle sociodemographic index (fig 1 and table S1). Similarly, most regions and countries had a declining trend in the age standardised mortality rate whereas several regions (eg, central Asia and Oceania) and countries (eg, Lesotho and Guatemala) showed an increasing trend (tables S1 and S3).

Figure S1 shows that the sociodemographic index level was positively associated with faster increases in the age standardised incidence rate and age standardised DALY rate for early onset type 2 diabetes between 1990 and 2019. The difference is equal to the age specific rate in men minus that in women, with a difference >0 meaning men have higher rates.

Fig 2 | Difference in age specific incidence between men and women by sociodemographic index (five categories; countries with a high, high-middle, middle, low-middle, or low sociodemographic index), from 1990 to 2019.
categories: behavioural (diets low in fruit, nuts and seeds, whole grains, and fibre; diets high in red meat, processed meat, and sweetened beverages; low physical activity; smoking; and secondhand smoke); environmental (low temperature, high temperature, household air pollution from solid fuels, and pollution from ambient particulate matter); and metabolic factors (high body mass index). Overall, high body mass index was the main attributable risk factor for all regions by sociodemographic index (fig 5). However, the contributions of different risk factors varied across regions (fig 6 and table S4). In 2019, compared with countries with a low sociodemographic index, DALY for early onset type 2 diabetes in countries with a high sociodemographic index were more attributable to high body mass index (84.42% v 52.08%), smoking (12.72% v 4.48%), pollution from ambient particulate matter (12.11% v 6.63%), low physical activity (9.14% v 2.74%), and diets high inprocessed meat (12.98% v 5.11%), red meat (11.09% v 3.04%), and sugar sweetened beverages (9.47% v 2.39%). In contrast, contributions to DALY were greater for household air pollution from solid fuels (17.25% v 0.07%) and diets low in fruits (8.59% v 6.16%) when countries with a low versus a high sociodemographic index were compared. The contribution of different risk factors did not vary with age, except for high body mass index, which had an increasing trend (fig 7 and table S5).

The top five attributable risk factors for DALY of early onset type 2 diabetes globally in 2019 for women were high body mass index, secondhand smoke, pollution from ambient particulate matter, household air pollution from solid fuels, and diet low in fruit. In men, the top five factors were high body mass index, pollution from ambient particulate matter, smoking, diet low in fruit, and secondhand smoke (fig 5 and table S6). Among the DALY attributable to tobacco, men were more affected by smoking (smoking v secondhand smoke 13.41% v 6.37%), whereas women were more affected by secondhand smoke (smoking v secondhand smoke 2.33% v 12.30%). Also, women were more affected by high body mass index (69.25% v 66.27%) and low physical activity (5.07% v 3.42%) than men.

From 1990 to 2019, the proportion attributable to high body mass index increased substantially from 45.01% to 69.25% in women and from 40.35% to 66.27% in men globally (fig S6 and tables S7-S8). The proportion attributable to all environmental risk factors decreased except for ambient particulate matter pollution and high temperature globally. The proportion attributable to pollution from ambient particulate matter only decreased in countries with a high sociodemographic index (from 12.89% to 11.13% in women and from 14.16% to 12.89% in men) but increased in all other sociodemographic index groups. For behavioural factors, the proportion attributable to diets high in sugar sweetened beverages and low physical activity increased globally and in all sociodemographic index regions, especially in countries with a high sociodemographic index (for sugar sweetened beverages, from 7.21% to 10.02%...
in women and from 6.50% to 9.04% in men; for low physical activity, from 8.68% to 12.21% in women and from 3.25% to 6.73% in men). The proportion attributable to tobacco use decreased markedly both globally and in all sociodemographic index groups.

**Discussion**

**Principal findings**

Early onset type 2 diabetes is increasingly prevalent and substantially affects the burden of disease. Based on data from the Global Burden of Disease Study 2019, our study showed a clear upward trend of the burden of early onset type 2 diabetes from 1990 to 2019. We found the highest burdens in countries with a low-middle and middle sociodemographic index; and among people aged <30 years, women were more susceptible to early onset type 2 diabetes. We also found that patterns of attributable risk factors for early onset type 2 diabetes varied across regions and countries. These findings provide a basis for understanding the epidemic nature of early onset type 2 diabetes and call for urgent actions to deal with the issue from a global perspective.

Previous studies have reported on the burden of early onset type 2 diabetes mostly in high income countries. A study in the US reported that the incidence of type 2 diabetes in adolescents aged 10-19 years increased from 9 cases per 100 000 persons in 2002-03 to 12.5 cases per 100 000 persons in 2011-12, with a 7.1% annual increase. A retrospective cohort study in the UK reported that among people with type 2 diabetes, the proportion of those with a diagnosis aged <40 years increased markedly from 5.9% in 1991-95 to 12.4% in 2006-10. In our analysis of early onset type 2 diabetes based on data from the Global Burden of Disease Study 2019, we have provided data for countries with a middle and low sociodemographic index, and found increasing trends in the age standardised incidence rate and age standardised DALY rate in adolescents and young adults aged 15-39 years globally and across all five categories of sociodemographic index. These findings indicate that the incidence and severity of early onset type 2 diabetes is increasing, and measures are urgently needed to control its spread in adolescents and young adults in almost every country.

**Burdens attributable to high body mass index**

Obesity is the main cause of type 2 diabetes. The prevalence of overweight and obesity has increased globally in all age groups, including children, adolescents, and young adults. Between 1990 and 2017, global deaths and DALY attributable to a high body mass index were estimated to have more than doubled, and for type 2 diabetes, the age standardised DALY rate and age standardised mortality rate attributable to high body mass index also increased by 80.4% and 73.5%, respectively. Similar results were found in our analysis; high body mass index was the main contributor to the burden of early onset type 2 diabetes and increased globally from 1990. Therefore, weight control and management are essential in reducing the burden of early onset type 2 diabetes.
Regional difference in the burden of early onset type 2 diabetes

Health outcomes and disease burdens were closely related to socioeconomic development, measured by the sociodemographic index.13 15 Our results also showed that large differences in the burden of early onset type 2 diabetes persisted across different categories of sociodemographic index, with an inverse U-shaped association between sociodemographic index and age-standardised incidence rate, age-standardised DALY rate, and age-standardised mortality rate, similar to the regional distribution of the burden of type 2 diabetes in all age groups.11 We found the highest age-standardised incidence rate and age-standardised DALY rate in countries with a low-middle and middle sociodemographic index between 1990 and 2019. Age-standardised mortality rate was unchanged in countries with a middle sociodemographic index and was even moderately increased in countries with a low-middle sociodemographic index, although we saw a downward trend in other categories of sociodemographic index. The greater disease burden in countries with a middle and low-middle sociodemographic index might be attributable to the rapid social and economic changes in these countries. For example, consumption of high energy beverages more than doubled in adolescents aged 12–18 years in Mexico between 1999 and 2006.27 Similar patterns of change were found in our study; increases in the proportion of DALY attributable to diets high in sugar sweetened beverages, processed meat, and red meat, and pollution from ambient particulate matter were seen in countries with a middle and low-middle sociodemographic index from 1990 to 2019. These transitions then led to changes in the disease spectrum: the disease burden in countries with a low-middle and middle sociodemographic index rapidly shifted from a predominance of communicable, maternal, neonatal, and nutritional diseases to non-communicable diseases and injury.13

In countries with a low-middle to middle sociodemographic index, however, levels of effective coverage index (an indicator of universal health coverage) for non-communicable diseases were far lower than that for communicable, maternal, neonatal, and nutritional diseases,28 which means that in these countries, changes in health systems were slower than epidemiological changes. Furthermore, countries with a low and low-middle sociodemographic index have had faster socioeconomic development than countries with a high-middle and high sociodemographic index since 2000,29 which could also contribute to the substantial increase in the burden of non-communicable diseases, such as early onset type 2 diabetes. Therefore, in countries with rapid transitions, more resources for the prevention and management of early onset type 2 diabetes are needed.

Because of the large differences in attributable risk factors for early onset type 2 diabetes across regions and countries, specific policies should be established to...
Fig 6 | Proportion of early onset type 2 diabetes disability adjusted life years (DALY) attributable to 15 risk factors in 2019 by sociodemographic index (five categories; countries with a high, high-middle, middle, low-middle, or low sociodemographic index)
Fig 7 | Proportion of early onset type 2 diabetes disability adjusted life years (DALY) attributable to 15 risk factors in 2019 by age group. NA=not applicable
deal with this epidemic more effectively. For example, in our analysis, we found that in countries with a high sociodemographic index, pollution from ambient particulate matter still accounted for a relatively high proportion (12.11%) of the burden of early onset type 2 diabetes, but the attributable fraction showed a downward trend, as well as the exposure level.14 Instead, problems like high consumption of unhealthy foods and physical inactivity are increasing and require special attention.

In contrast, for less socioeconomically developed countries, measures to improve the availability, accessibility, and affordability of healthy foods and household conditions were recommended. We also found that countries with a low sociodemographic index had the highest age standardised mortality rate despite the lowest age standardised incidence rate, probably because of poorer quality of basic diabetes care, such as less variety and higher cost of insulin in these countries.30 Therefore, increasing the investment in basic diabetes care in these countries is needed. Also, socioeconomic change has been faster in countries with a lower sociodemographic index,29 and so these countries are likely to face similar problems to countries with a middle and high sociodemographic index in the next decades. Nevertheless, some public health interventions implemented in countries with a high sociodemographic index have been shown to be effective, such as tax on cigarettes31 and regulation of air quality.12 33 Therefore, countries at the stage of rapid socioeconomic change can learn from these successful initiatives.

Sex and age differences in the burden of early onset type 2 diabetes

We found that age was an important modification factor affecting differences between the sexes for the burden of early onset type 2 diabetes: in people aged <30 years, mortality and DALY were higher in women than in men, but the reverse was true for those aged >30 years. We suspect that pregnancy and polycystic ovary syndrome in women, which are associated with insulin resistance,34 35 could partly contribute to the differences between the sexes. We also found that the higher disease burden in women was more pronounced in countries with a low rather than a high sociodemographic index. This finding could be because in less developed countries, girls and women might have less access to healthcare services and worse metabolic health than boys and men, including glycaemic control.36 Poor glycaemic control during the common reproductive period for women (ie, age <30 years) could cause hyperglycaemia in pregnancy and adverse outcomes for offspring. Therefore, effective prevention and management of type 2 diabetes in women aged <30 years should be further strengthened, especially in less developed regions.

Strong evidence has indicated that physical inactivity and obesity increase the risk of type 2 diabetes.37 38 Compared with boys and men, girls and women were less physically active,39 40 and in adults, the global prevalence of obesity was generally higher for women than for men in all age groups.41 Our analysis also indicated that high body mass index and low physical activity contributed more to the burden of early onset type 2 diabetes in women than in men. Although the global prevalence of smoking has decreased since the 1970s, secondhand smoke is a major public health problem, and an analysis of the Global Youth Tobacco Survey reported that the prevalence of secondhand smoke in public places was increasing in adolescents aged 12-16 years and the increase was greater in girls.42 Another study based on data from the Global Burden of Disease Study reported that among the global deaths from secondhand smoke, 47% were in women, 28% in children, and 26% in men in 2004.43 In our study, the proportional DALY for secondhand smoke was 12.30% in women and 6.37% in men, further indicating the importance of preventing secondhand smoke, especially in women. Taken together, differences in several risk factors for early onset type 2 diabetes between men and women should be considered in policy making.

Strengths and limitations of this study

We have comprehensively evaluated the global, regional, and national temporal trends for early onset type 2 diabetes and the corresponding contributions of risk factors based on the Global Burden of Disease Study 2019. However, our study had several limitations. Firstly, our results are subject to the methodological defects of the Global Burden of Disease Study 2019. Where data were not available, the results depended on the out-of-sample predictive validity of the modelling efforts; even when data were available, the preferred case definition or measurement method might not have been used (eg, large variations still existed in the definition of type 2 diabetes across the data sources). Several techniques to reduce bias and inaccuracy were used in the Global Burden of Disease Study 2019, but bias cannot be fully ruled out. Also, we estimated confidence intervals rather than uncertainty intervals for rates after age standardisation. Therefore, our results should be interpreted with caution, and more real world studies are needed to verify our findings. Secondly, the fatal and non-fatal burdens of early onset type 2 diabetes relied on the detection methods, quality of screening, and data registry, which also depended on socioeconomic level. Because of the large differences in healthcare services across countries, the burden of early onset type 2 diabetes in countries with a low sociodemographic index was likely to be underestimated. Thirdly, 15 years was the age threshold for type 2 diabetes in the Global Burden of Disease Study 2019, and so children and adolescents aged <15 years were not included in our analysis. The incidence of type 2 diabetes in those aged <15 years was uncommon, however, and we believe that inclusion of this young age group would not have changed our main findings.
Conclusions

Early onset type 2 diabetes is a growing health problem globally, especially in countries with a low-middle and middle sociodemographic index. Women aged <30 years need special attention for intervention measures. High body mass index was the main attributable risk factor for the burden of early onset type 2 diabetes in all countries over the past 30 years. Also, the variable attributable risk factors for type 2 diabetes in adolescents and young adults in countries with different levels of socioeconomic development highlight the importance of specific measures to deal with this growing global health problem.

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Contributors: FW and AP contributed equally to this work. JW and JX conceived the idea, designed the study, and drafted the manuscript. MW, FW, and AP assisted in the study design, and drafted the manuscript. JW, FW, and AP supervised and coordinated the data collection. AP, GL, and YC double checked the data and results. MW, AP, FW, and GL obtained funding. All authors have read and approved the final manuscript. FW and AP are guarantors for this study. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

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17 Knott C, Bell S, Britton A. Alcohol consumption and the risk of type 2 diabetes: a systematic review and dose-response meta-analysis of more than 1.9 million individuals from 38 observational studies. Diabetes Care 2015;38:1804-12. doi: 10.2337/dc15-0710