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Original article

Burden of diabetes, hyperglycaemia in China from to 2016: Findings from the 1990 to 2016, global burden of disease study

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ABSTRACT

Aims. – The prevalence of diabetes in China is among the highest in the world. For this reason, findings from the 2016 Global Burden of Disease (GBD) study were used to calculate the burden of hyperglycaemia and diabetes in China.

Methods. – Following the general analytical strategy used in GBD 2016, diabetes prevalence and mortality were analyzed by age and gender. Trends in disability-adjusted life years (DALYs) due to diabetes were assessed in 33 province-level administrative units from 1990 to 2016, and similar data were provided for chronic kidney disease (CKD) related to diabetes and, as an overall summarizing measure, for hyperglycaemia expressed as high fasting plasma glucose (HFPG).

Results. – From 1990 to 2016, all-age prevalence of diabetes rose from 3.7% to 6.6%, and all-age diabetes and diabetes-related CKD mortality rates increased by 63.5% and 33.3%, respectively, with both rates increasing more rapidly in diabetes patients aged 15–49 years than in any other age groups. In 2016, HFPG became China's sixth leading cause of DALYs, and the attributable DALYs burden was 1802.3/100,000 population. Although the number of diabetes DALYs increased by 95% from 1990 to 2016, age-standardized diabetes DALYs rates increased by only 2.3%. Also, from 1990 to 2016, rates of age-standardized DALYs due to diabetes decreased in 14 provinces, but increased in 19 provinces. High BMI Scores and diets low in whole grains, nuts and seeds were the most important risk factors for diabetes in 2016.

Conclusion. – Diabetes and hyperglycaemia constitute a huge health burden in China. The substantial increase in diabetes-related burden represents an ongoing challenge, given the rapidly ageing Chinese population. Thus, a targeted control and preventative strategy needs to be developed at risk factor level to reduce this burden.

Introduction

Currently, non-communicable diseases (NCDs) are the main threats to health amongst the world's population. An estimated 39.5 million deaths, or 72.3% of global deaths, were due to NCDs in 2016, while the number of disability-adjusted life years (DALYs) from NCDs increased by 36.6% from 1990 to 2016 [1,2]. The World Health Organization (WHO) has identified diabetes mellitus as one of the four main NCDs meriting close attention [3,4], as the number of deaths due to diabetes increased by 31.1% between 2006 and 2016 globally. Most of the diabetes burden now falls on low- and middle-income countries, thereby covering most of the world's population, with dramatic rises in both the incidence and prevalence of diabetes over recent decades [5,6].

The 2017 International Diabetes Federation IDF Diabetes Atlas 8th ed. estimated that, in that year, the number of diabetes patients in China was 114 million, equating to nearly a quarter of cases worldwide (425 million) [7], while nationwide epidemiological surveys have revealed that the prevalence of diabetes has increased especially rapidly over the last 10 years [8–11]. Population ageing, urbanization, industrialization, changes in nutri-

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Abbreviations

GBD	Global Burden of Disease (study)
NCDs	non-communicable diseases
DALYs	disability-adjusted life years
IDF	International Diabetes Federation
YLLs	years of life lost (due to premature mortality)
YLDs	years lived with disability
HFPG	high fasting plasma glucose
CKD	chronic kidney disease

tion, epidemics of obesity and low levels of physical activity are all contributors to this increase [12]. In 2013 in China, the estimated overall prevalence of diabetes among adults was 10.9%, while that of prediabetes was 35.7% [13].

Given these trends of diabetes prevalence in China, it is now necessary to investigate the burden of diabetes to inform the current public-health policies and provide guidance for disease-preventative and health-promoting strategies in future. Thus, the objective of the present report is to describe the current status and trends for the health burden of diabetes and hyperglycaemia in China, based on the results of the 2016 Global Burden Disease (GBD) study.

Methods

Data sources

The GBD 2016 study, which included injuries and risk factors, covered 195 countries and territories between 1990 and 2016. In total, 328 causes of disease and injury, 264 causes of death and 84 risk factors were systematically analyzed. Details of the methodology used in GBD studies in general, and the main changes incorporated into the GBD 2016 methods, have been explained elsewhere [1,2,14,15].

The data originally adapted by the GBD 2016 collaborators to estimate diabetes outcomes in China were mostly from three data sources: China Health and Nutrition Survey; China Chronic Disease and Risk Factor Surveillance; and China National Diabetes and Metabolic Disorders Study. GBD 2016 looked at the burden of hyperglycaemia in terms of both its cause (diabetes) and as a risk factor, expressed as high fasting plasma glucose (HFPG), which also encompassed the effects of lower levels of hyperglycaemia. Part of the burden was considered to be diabetes-defined as per the International Statistical Classification of Diseases and Related Health Problems, 10th revision (ICD-10) Codes E10–13 – excluding the '0.2' Codes related to chronic kidney disease (CKD) – and included living with diabetes ('uncomplicated diabetes') and its traditional 'microvascular' complications (such as vision loss due to severely poor vision and blindness, neuropathy and amputation) [16]. The rest of the burden, resulting from other recognized complications of both diabetes and HFPG [14], such as tuberculosis, colorectal, liver, pancreatic, lung, breast, ovarian and bladder cancers, ischaemic heart disease, stroke, Alzheimer's disease and other dementias, peripheral artery disease, CKD and sensory-organ diseases, was accounted for by HFPG. For these latter calculations, the theoretical minimum risk exposure level of glucose was considered to be 4.8–5.4 mmol/L (86.4–97.2 mg/dL).

Risk factors

GBD 2016 also identified, through analyses of systematic reviews, diabetes risk factors such as high body mass index (BMI) scores, low levels of physical activity, diets low in whole grains, nut, seeds and fruit, diets high in red and processed meat, high intakes of sweetened beverages, alcohol consumption and smoking, the latter most using a time lag. The diabetes burden fraction attributable to each factor was calculated as previously described elsewhere [16–18].

Prevalence, mortality, DALYs and population attributable fractions

The general methodological approaches used in GBD 2016, and the specific methodology used for diabetes in China, have been described elsewhere [1,14,15]. In China, prevalence, mortality and DALYs were used to measure the burden of diabetes and diabetes-related CKD. DALYs measure loss of health due to both fatal and non-fatal disease burden, and were calculated by summing up the years of life lost (YLLs) due to premature mortality and years lived with disability (YLDs). In brief, YLLs were based on remaining life expectancy compared with a reference standard life table at age of death [1], while YLDs were calculated by multiplying the prevalence of disease or injury and its main disabling outcomes by its weighted level of severity. Disability weighting was derived from general population-based surveys [19], and all-age standardized results were calculated based on the GBD reference population [2].

The population attributable fraction (PAF) represents the proportion of outcomes that would be reduced in any given year if exposure to a risk factor in the past had been reduced to the counterfactual level of theoretical minimum risk exposure [14].

Uncertainty intervals

Our present report calculated the 95% uncertainty interval (UI) for each quantity used in the analyses. These UIs were estimated by taking 1000 samples from the posterior distribution of each quantity, and using the 25th- and 975th-ordered draws of the uncertainty distribution.

Results

Diabetes prevalence and mortality

From 2000 to 2016, the number of diabetes cases in China increased by 62.7% from 55,167,473 (95% UI: 49,860,584–61,094,047) to 89,783,100 (95% UI: 81,972,992–97,771,632). Thus, in 2016, nearly 90 million Chinese had diabetes. Fig. 1 a shows that, from 1990 to 2016, all-age prevalence rates rose by 78.4% from 3.7% (95% UI: 3.3–4.0%) to 6.6% (95% UI: 6.0–7.2%), and age-standardized prevalence rates increased up to 2005, after which it decreased; nevertheless, from 1990 to 2016, it rose by 17.4% from 4.6% (95% UI: 4.2–5.1%) to 5.4% (95% UI: 5.0–5.9%). Its present prevalence rate is closely similar to the worldwide 5.5% GBD 2016 estimate.

A total of 140,838 diabetes deaths (95% UI: 135,939–145,569) occurred in 2016 in China, 51.0% of them being men; this percentage was higher than the global male percentage (47.1%). The all-age diabetes mortality rate per 100,000 population increased by 63.5% from 6.3 (95% UI: 6.0–6.8) in 1990 to 10.3 (95% UI: 9.9–10.6) in 2016. Likewise, the age-standardized mortality rate per 100,000 increased slightly from 10.8 (95% UI: 10.2–11.7) in 1990 to 13.2 (95% UI: 12.7–13.8) in 2000, after which it declined to 10.0 (95% UI: 9.7–10.3) in 2016 (Fig. 1a).

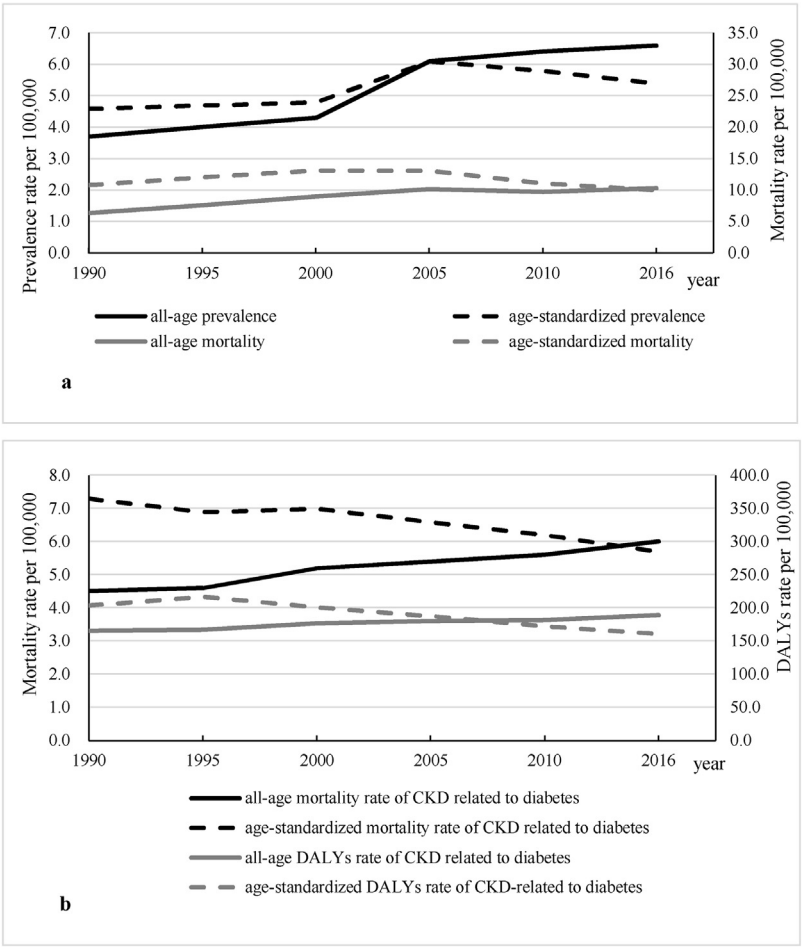

Fig. 1. Trends in China from 1990 to 2016 for: (a) all-age and age-standardized prevalence and mortality rates of diabetes; and (b) all-age and age-standardized mortality and disability-adjusted life years (DALYs) rates for chronic kidney disease (CKD) due to diabetes.

Table 1 presents the number of cases and prevalence rates of diabetes by gender and age in 1990 and in 2016: case numbers increased by 116.3%, especially in people aged ≥ 50 years, whereas diabetes prevalence in those aged 15–49 years rose faster than in any other age groups. Table 2 shows that, over the same time period, the total number of deaths due to diabetes nearly doubled, especially in men aged ≥ 50 years and women aged ≥ 70 years, while mortality rates increased by 13.9% and 25.2% in men aged 15–49 years and ≥ 70 years, respectively. Compared with 1990, mortality rates among women of all ages declined except for those aged ≥ 70 years in 2016. Thus, in 2016, mortality rates among men of all ages were higher than in women.

DALYs

From 1990 to 2016, the number of DALYs increased by 95% from 4,274,697.2 (95% UI: 3,421,182.5–5,362,338.3) to 8,337,262.8 (95% UI: 6,482,105.6–10,685,383.3). In contrast, age-standardized rates of DALYs due to diabetes increased by only 2.3% from 502.0 (95% UI: 408.9–620.7) to 513.7 (95% UI: 400.8–656.7) per 100,000, thereby suggesting that population growth and ageing were probably the main drivers of the observed increase in total numbers of DALYs related to diabetes.

Provincial-level age-standardized rates of DALYs per 100,000 in 1990 and 2016 are shown in Fig. 2. In 2013, rates in the Northern and Southwestern regions of China were comparatively lower than in the Southern, Northwestern and Northeastern regions (Fig. 2a). Tianjin, Xinjiang and Liaoning had the highest age-standardized rates of DALYs at > 650.0/100,000 population, whereas Hong Kong, Hubei and Zhejiang had the lowest age-standardized DALYs rates. The pattern for 2016 revealed that provinces with relatively higher age-standardized rates of DALYs were mostly clustered in the Northeast and Northwest of China (Fig. 2b): Tianjin had the highest rates at 696.1/100,000, followed by Xinjiang and Liaoning whereas, again, Hong Kong, Zhejiang and Hubei had the lowest rates.

As for changes between 1990 and 2016, age-standardized DALYs rates decreased the most in the South, Southwestern and Northeastern regions of China (Fig. 2c): 14 provinces displayed downward trends while the most rapid decreases were in Hong Kong, Guangdong and Fujian. In contrast, the other 19 provinces showed upward trends, with Beijing, Qinghai and Shandong having the fastest growth rates.

Risk factors

Table 3 presents the 2016 PAFs of diabetes DALYs and deaths according to each risk factor as well as rates of diabetes DALYs and deaths due to these risk factors. There is no significant association with alcohol consumption. Other than HFPG, which led to diabetes only, high BMIs and diets low in whole grains, nuts and seeds were the leading factors attributable to diabetes-related DALYs and deaths.

Diabetes-related CKD

The separate GBD study category for CKD due to diabetes has allowed specific evaluation of this diabetes burden. In 2016,

Table 1
Case and prevalence rates of diabetes in China by age and gender between 1990 and 2016.

Age group	Cases (*n*)			Prevalence (%)		
	1990	2016	Change (%)	1990	2016	Change (%)
All ages	41,507,113.6 (37,259,363.3–45,830,296.3)	89,783,100.6 (81,972,991.6–97,771,632.0)	116.3	3.7 (3.3–4)	6.6 (6–7.2)	78.4
Men						
< 5 years	827.5 (397.1–1,516.3)	446.9 (216.2–857.2)	−46.0	–[a]	–[a]	–[a]
5–14 years	127,306.5 (87,893.2–175482.1)	114,215.6 (76,449.2–16,2542.5)	−10.3	0.1 (0.1–0.2)	0.1 (0.1–0.2)	–[a]
15–49 years	11,975,279.7 (10,312,659.3–13,788,884.3)	22,255,312.0 (19,574,442.2–25,111,983.2)	85.8	3.6 (3.1–4.2)	5.8 (5.1–6.5)	61.1
50–69 years	8,071,402.2 (7,229,048.4–9030403.4)	20,587,603.3 (18,686,875.3–22570548.3)	155.1	10.8 (9.6–12.1)	12.7 (11.5–13.9)	17.6
> 70 years	2,169,689.3 (1,946,397.1–2,407,896.7)	5,805,009.2 (5,257,079.7–6,427,260.9)	167.6	13.0 (11.6–14.4)	14.7 (13.3–16.3)	13.1
Women						
< 5 years	887.0 (423.8–1,691.9)	382.2 (183.7–721.0)	−56.9	–[a]	–[a]	–[a]
5–14 years	117,417.7 (80,977.0–163,890.4)	83,379.6 (55,686.3–118,402.0)	−29.0	0.1 (0.1–0.2)	0.1 (0.1–0.2)	–[a]
15–49 years	8,527,229.5 (7,303,259.7–9,812,406.5)	14,212,435.7 (12,408,546.3–16,178,128.5)	66.7	2.7 (2.3–3.1)	3.9 (3.4–4.5)	44.1
50–69 years	7,515,363.9 (6,686,917.8–8,441,501.0)	19,468,519.9 (17,692,679.6–21,334,903.4)	159.0	10.9 (9.7–12.2)	12.3 (11.1–13.4)	12.8
> 70 years	3,001,710.1 (2,651,955.3–3,398,541.6)	7,255,796.1 (6,520,445.8–8,048,977.2)	141.7	14.2 (12.6–16.1)	16.4 (14.7–18.2)	15.5

Data in parentheses are 95% uncertainty intervals.
[a] < 0.1.

82,605.2 (95% UI: 73,573.2–91,634.2) people died of CKD related to diabetes in China. The trend for all-age and age-standardized mortality rates of diabetes-related CKD is shown in Fig. 1b. Between 1990 and 2016, the all-age mortality rate due to CKD in diabetes increased by 33.3% from 4.5 (95% UI: 4.1–5.3) to 6.0 (95% UI: 5.4–6.7) per 100,000 while the age-standardized CKD mortality rate caused by diabetes in China in 2016 was 5.7 (95% UI: 5.1–6.4) compared with the global level of 7.6 (95% UI: 6.9–8.3) per 100,000.

On considering not just deaths, but also disability in China, the all-age DALYs rate per 100,000 population increased by 14.5% from 165.2 (95% UI: 147.5–187.4) in 1990 to 189.1 (95% UI: 168.2–210.7) in 2016 (Fig. 1b). In addition, the age-standardized DALYs rate was 160.8 (95% UI: 143.3–178.9) in 2016 compared with the global level of 209.2 (95% UI: 188.9–230.8) per 100,000.

HFPG

DALYs because of HFPG represented 7.7% of all DALYs and 13.0% of NCD DALYs in 1990. By 2016, these relative burdens had climbed to 15.8% and 18.2%, respectively. Also, in that year, HFPG was the sixth leading cause of overall DALYs, with an attributable DALYs burden of 1802.3 (95% UI: 1433.2–2205.7) per 100,000. The three

Table 2
Number of deaths and mortality rates for diabetes by age and gender in China from 1990 to 2016.

Age group	Deaths (*n*)			Mortality rate per 100,000		
	1990	2016	Change (%)	1990	2016	Change (%)
All ages	71,694.9 (68,196.8–77,242.1)	140,838.7 (135,939.3–145,569.8)	96.4	6.3 (6.0–6.8)	10.3 (9.9–10.6)	63.5
Men						
< 5 years	275.6 (241.4–314.8)	35.6 (30.2–42.9)	−87.1	0.5 (0.4–0.6)	0.1 (0.1–0.2)	−77.7
5–14 years	141.8 (128.5–158.3)	46.3 (41.6–51.7)	−67.3	0.1 (0.1–0.2)	0.1 (0.05–0.1)	−59.6
15–49 years	4405.6 (4109.9–4848.8)	5843.7 (5553.4–6159.1)	32.6	1.3 (1.2–1.5)	1.5 (1.4–1.6)	13.9
50–69 years	13,790.4 (13,047.4–14,794.3)	28,927.7 (27,607.0–30,191.2)	109.8	18.4 (17.4–19.7)	17.8 (17.0–18.6)	−3.0
≥ 70 years	12,513.2 (11,825.8–13,431.8)	37,017.5 (35,473.5–38,674.8)	195.8	74.8 (70.7–80.3)	93.7 (89.7–97.8)	25.2
Women						
< 5 years	407.9 (342.2–493.0)	34.2 (28.0–43.2)	−91.6	0.8 (0.7–0.9)	0.1 (0.1–0.2)	−84.6
5–14 years	231.4 (206.3–266.2)	55.4 (47.7–64.6)	−76.1	0.2 (0.2–0.3)	0.1 (0.05–0.1)	−67.5
15–49 years	3958.6 (3683.5–4319.2)	3390.7 (3157.4–3626.4)	−14.3	1.3 (1.2–1.4)	0.9 (0.9–1.0)	−25.4
50–69 years	17,395.2 (16,071.6–19,159.9)	26,347.4 (24,813.8–27,919.1)	51.5	25.1 (23.2–27.7)	16.6 (15.6–17.6)	−34.0
≥ 70 years	18,575.1 (16,995.7–21,337.6)	39,140.2 (36,904.4–41,380.7)	110.7	88.1 (80.6–101.2)	88.3 (83.2–93.3)	0.2

Data in parentheses are 95% uncertainty intervals.

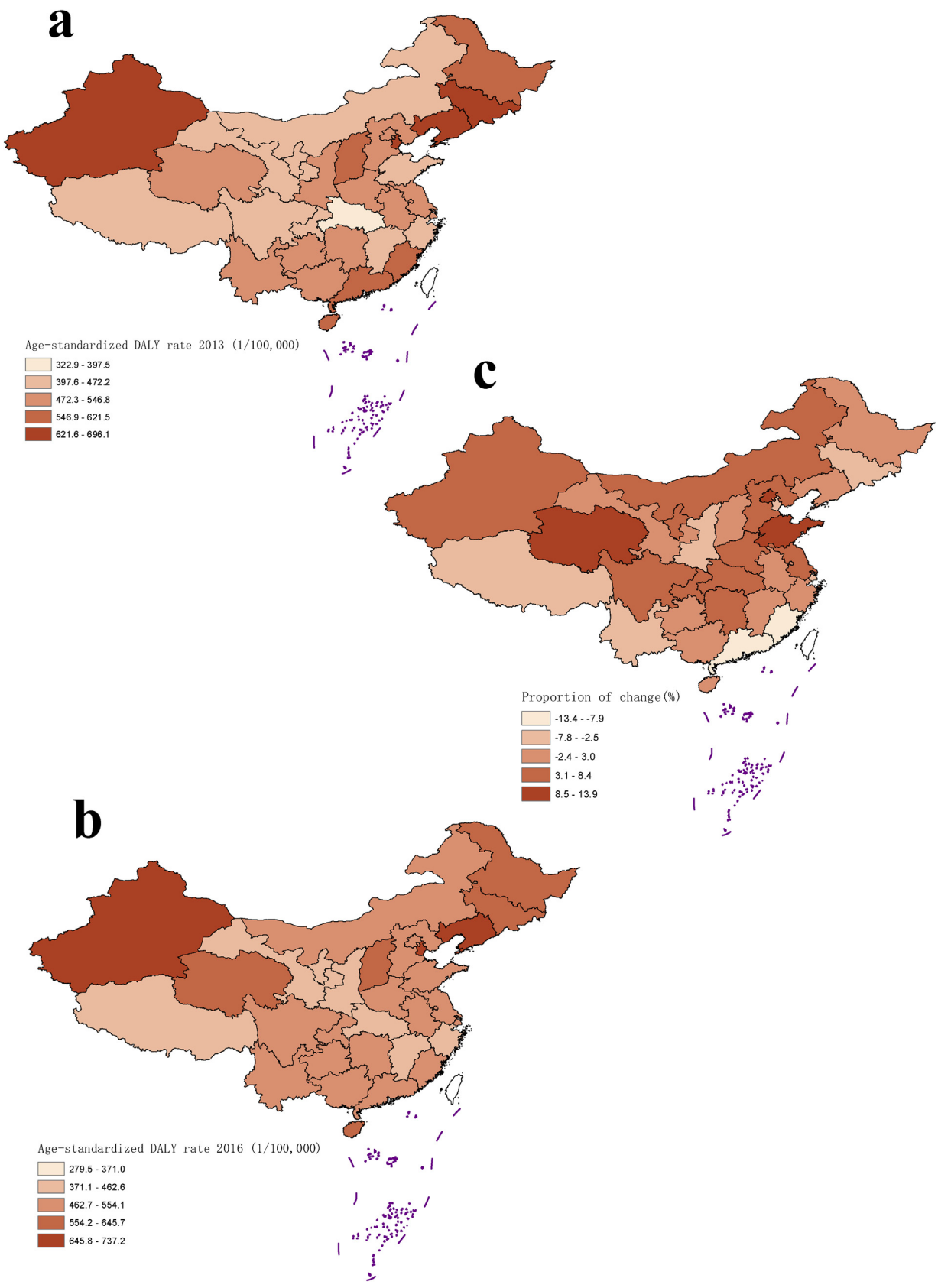

Fig. 2. Diabetes-related age-standardized disability-adjusted life years (DALYs) rates per 100,000 population in China at the provincial level in (a) 2013 and (b) in 2016, and (c) changes in these DALYs rates from 1990 to 2016.

Table 3
Population attributable fractions (PAFs) for disability-adjusted life years (DALYs) and deaths related to diabetes, and diabetes health burden due to various risk factors in China (2016).

Risk factors	PAFs		Attributable diabetes burden (per 100,000)	
	DALYs (%)	Deaths (%)	Rate of DALYs	Rate of deaths
High fasting plasma glucose	100	100	609.9 (474.2–781.7)	10.3 (9.9–10.6)
Diet high in processed meat	0.3 (0.01–1.1)	0.2 (0.0–0.7)	1.6 (0.0–6.9)	0.02 (0.0–0.1)
Diet high in red meat	3.7 (0.6–6.5)	2.6 (0.4–4.6)	22.8 (3.3–41.9)	0.3 (0.04–0.5)
Diet high in sugar-sweetened beverages	0.1 (0.1–0.2)	0.1 (0.04–0.1)	0.8 (0.5–1.3)	0.01 (0.0–0.01)
Diet low in fruit	9.9 (2.2–19.3)	7.7 (1.7–15.2)	60.4 (11.9–124.6)	0.8 (0.2–1.6)
Diet low in nuts and seeds	13.6 (6.8–21.2)	10.8 (5.4–17.0)	83.1 (40.6–139.5)	1.1 (0.5–1.7)
Diet low in whole grains	19.6 (10.5–30.3)	15.7 (8.3–24.3)	119.7 (59.6–195.3)	1.6 (0.8–2.5)
High body mass index	39.4 (22.3–56.9)	28.6 (15.0–44.0)	241.4 (125.4–388.5)	2.9 (1.5–4.5)
Low physical activity	2.2 (0.5–4.1)	2.5 (0.5–4.7)	13.4 (3.1–25.7)	0.3 (0.1–0.5)
Second-hand smoke	7.4 (2.9–11.2)	8.2 (3.2–12.5)	45.4 (16.8–72.8)	0.8 (0.3–1.3)
Smoking	8.5 (2.3–14.8)	7.7 (2.1–13.4)	51.7 (14.7–92.6)	0.8 (0.2–1.4)

Data in parentheses are 95% uncertainty intervals.

leading conditions of DALYs attributable to HFPG were diabetes, stroke and ischaemic heart disease (Table 4), while the top five PAFs of HFPG included 66.2% (95% UI: 60.3–72.5) of CKD DALYs, 21.9% (95% UI: 19.4–24.6) of peripheral artery disease DALYs, 16.3% (95% UI: 10.0–24.8) of ischaemic heart disease DALYs, 15.6% (95% UI: 10.2–22.3) of stroke DALYs and 8.9% (95% UI: 5.6–12.4) of tuberculosis DALYs, as well as 100% of diabetes DALYs (as our study assumption).

During the 1990–2016 period, the mortality rate attributable to HFPG increased by 59.6% from 41.9 (95% UI: 31.9–55.1) to 66.9 (95% UI: 49.6–86.6) per 100,000. In 2016, a number of deaths and mortality rates of different diseases due to HFPG (Table 4) included ischaemic heart disease, stroke and diabetes as the three leading causes of death. In that year, the PAF of HPFG was 9.5% of all-causes deaths, whereas the top five PAFs were 66.6% (95% UI: 59.7–73.7) of CKD deaths, 19.6% (95% UI: 16.9–22.5) of peripheral artery disease deaths, 16.7% (95% UI: 9.5–27.3) of ischaemic heart disease deaths, 15.1% (95% UI: 9.9–22.9) of stroke deaths and 9.3% (95% UI: 5.5–13.6) of tuberculosis deaths, as well as 100% of diabetes deaths (as our study assumption).

Discussion

The present study was a comprehensive evaluation of the large and ever-growing burden of diabetes and HFPG, including CKD, in China. The all-age prevalence of diabetes in this study was 6.6% and China, which has the world's largest population, ranks number one for having the greatest number of people with diabetes in the

Table 4
Disability-adjusted life years (DALYs) and deaths due to various diseases attributable to high fasting plasma glucose (HFPG) in China (2016).

Diseases	DALYs		Deaths	
	Numbers	DALYs (rate/100,000)	Numbers	Mortality (rate/100,000)
Diabetes	8,337,262.9 (6,482,105.6–10,685,383.3)	609.9 (474.2–781.7)	140,838.7 (135,939.3–145,569.8)	10.3 (9.9–10.6)
Stroke	6,006,642.0 (3,938,506.9–8,687,827.8)	439.4 (288.1–635.5)	269,992.3 (175,559.4–406,247.1)	19.8 (12.8–29.7)
Ischaemic heart disease	4,840,940.4 (2,941,543.6–7,382,020.3)	354.1 (215.2–540.0)	287,594.0 (162,195–466,073.4)	21.0 (11.9–34.1)
Chronic kidney disease	3,303,261.6 (2,897,011.5–3,731,337.9)	241.6 (211.9–273.0)	111,611.8 (97,848.4–125,508.6)	8.2 (7.2–9.2)
Tracheal, bronchial, lung cancers	787,624 (172,830.2–1,771,623.4)	57.6 (12.6–129.6)	37,782.6 (8415.3–84,621.0)	2.8 (0.6–6.2)
Alzheimer's disease, other dementias	465,914.1 (95,762.4–1,057,689.0)	34.1 (7–77.4)	33,742.6 (7066.7–75,753.3)	2.5 (0.5–5.5)
Colorectal cancers	224,825.9 (50,548.5–501,441.6)	16.4 (3.7–36.7)	10,710.8 (2451.4–23,738.2)	0.8 (0.2–1.7)
Liver cancer	170,347.2 (34,632.3–405,648.9)	12.5 (2.5–29.7)	6681.1 (1333.2–16,150.9)	0.5 (0.1–1.2)
Tuberculosis	154,277.1 (94,291.8–218,383.2)	11.3 (6.9–16.0)	3737.3 (2158.3–5539.4)	0.3 (0.2–0.4)
Breast cancer	99,602.2 (18,402.7–237,274.1)	7.3 (1.3–17.4)	3730.7 (695.5–8804.3)	0.3 (0.1–0.6)
Pancreatic cancer	98,611.4 (22,036.7–217,935.2)	7.2 (1.6–15.9)	4634.7 (1027.5–10,180.8)	0.3 (0.1–0.7)
Sensory-organ disorders	62,401.9 (13,734.5–147,159.7)	4.6 (1–10.8)	0	0
Bladder cancer	30,617.3 (6009.3–69,816.8)	2.2 (0.4–5.1)	1713.8 (342.1–3865.9)	0.1 (0–0.3)
Peripheral artery disease	27,988.0 (16,646.6–45,365.8)	2.0 (1.2–3.3)	432.0 (336.4–559.3)	0
Ovarian cancer	27,217.1 (4924.3–64,621.1)	2.0 (0.4–4.7)	1078.5 (197.7–2566.8)	0.1 (0–0.2)

Data in parentheses are 95% uncertainty intervals.

world [20,21]. Based on data from national surveys, the estimated prevalence of diabetes in adults was 2.6% in 2002 [10], but just 5 years later, this had increased rapidly to 9.7% in 2007 [22] and 10.9% in 2013 [13]. Of note, recent estimates of diabetes prevalence have included an additional criterion based on HbA1c levels. In addition, from 1990 to 2013, the prevalence rate in people aged 15–49 years had particularly increased, making the overall diabetes population younger. Compared with Western populations, diabetes in China has been characterized by rapid increases in recent years, with relatively early disease onset and low rates of diabetes awareness and treatment [12]. Thus, health education and interventions dealing with diabetes need to be implemented among China's working-age population.

Yet, even though the age-standardized mortality rate for all NCDs declined more rapidly from 1990 to 2016 in China (37.4%) compared with the overall global decline rate (25.1%) [1], all-age mortality rates due to diabetes – an important component of the NCD global burden – nevertheless increased in most developing countries [17,18], including China. Also, in addition to the overall increase of diabetes at the national level, a significant upward trend was noted in men aged 15–49 years and $\geq$ 70 years from 1990 to 2016. Health outcomes in men compared with women are consistently poorer, as women are more responsive to health information, and better at seeking healthcare and obtaining access to primary prevention than men [21]. Compared with 1990, mortality rates in women aged $<$ 70 years and boys aged $<$ 15 years declined in 2016. Indeed, mortality rates for all people aged $<$ 15 years fell rapidly; this declining mortality could be associated with improved access to community- and school-based healthcare.

The age-standardized DALYs rate decreased in 14 provinces, but increased in 19 others from 1990 to 2016. These regional differences were partly caused by different distributions of risk factors for diabetes in each province. Thus, the level of exposure to diabetes risk factors should be estimated at the provincial level to better explain the disparate variations in diabetes burden. Moreover, the different DALYs by province have important public-health implications. Given limited health resources, targeted cost-effective interventional strategies and prioritized programmes are essential.

Over the past 30 years, Chinese society has undergone rapid improvements, with demographic transitions and lifestyle changes having a major impact on public health [23]. Although the burden of communicable diseases has fallen rapidly, the burden of NCDs such as diabetes, attributable to individual behaviours and practices, is steadily increasing. Diabetes is 100% attributed to HFPG, and is also the cause of other complications such as ischaemic heart disease, stroke and CKD, among others. The HFPG burden of both DALYs and mortality grew considerably from 1990 to 2016, and high BMI Scores and unhealthy diets and lifestyles are risk factors for HFPG. High BMIs are also important risk factors for cardiovascular disease, several cancers and musculoskeletal disorders [24–29]. In fact, the continuing upward trend towards high BMIs in the Chinese population has pushed China from 60th and 41st places for men and women, respectively, in the 1975 worldwide ranking for numbers of severely obese people to second place for both genders in 2014 [30]. Indeed, BMI has become the number-one risk factor for diabetes in China. Although grains are staples among the Chinese population [31], carbohydrates as a percentage of total energy intake decreased from 68.8% in 1991 to 60% in 2014 [32]. Moreover, the majority of grains consumed in China are refined, such as white rice and refined wheat flour, and constitute a major contributor to dietary glycaemic load [33]. As high intakes of refined grains have consistently been associated with an increased risk of diabetes [34,35], higher intakes of whole grains should now be encouraged and popularized in China. However, other diabetes-related dietary factors give no cause for optimism, as consumption levels of healthy dietary factors such as nuts, seeds and fruit remain low [36,37]. In addition, smoking and physical inactivity are also important contributors to the diabetes burden.

The China Da Qing Diabetes Prevention Study indicated that lifestyle interventions are an effective way to reduce the incidence of diabetes [38]. To slow or even stop the growing diabetes epidemic in China, policies such as Healthy China 2030 and long-term plans for the prevention and treatment of chronic diseases (2017–2025) have been put in place. Likewise, interventional projects such as China Healthy Lifestyle for All and National Demonstrative Districts for NCD Prevention and Control have also been implemented, with primary care as another platform for delivery of interventions such as the detection and pharmacological management of HFPG and impaired glucose tolerance, as well as diabetes screening and management. Effective policies need to be multi-sectorial, engaging other groups such as departments of social welfare, employment and education, and mass media. Indeed, the prevention and control of diabetes and HFPG will not only improve the health of the general population, but also contribute to the sustainable development of the Chinese economy and society.

Our study has several strengths. It offers the most up-to-date and accurate information on the health burdens of hyperglycaemia and diabetes in China, and provides a reference point for healthcare policy-makers. In particular, the standardized methods for estimating the hyperglycaemia and diabetes metrics used in the GBD 2016 study allow comparisons on a global scale as well as at provincial levels in each country studied. In addition to revealing the major trends in diabetes prevalence and mortality at the national level, our findings also illustrate important variations in DALYs among China's provinces.

However, a number of important limitations should also be noted. First, as the data for this study were mostly from GBD 2016, all the general limitations ascribed to that study's methodologies also apply here [1,2,14,15]. Second, while the burden of diabetes in China's provinces was estimated using the standard GBD methodology to ensure comparability, there were inevitable measurement errors in the process that may have increased the inaccuracy of estimated results, thereby possibly masking or diminishing significant trends. Third, there was no differentiation between diabetes subtypes in this study: as the prevalence of T1D is low, the results apply mainly to T2D. Finally, while most previous studies were limited to adults, our study covered all age-groups.

Conclusion

The burden of hyperglycaemia and diabetes increased rapidly in China between 1990 and 2016. Thus, programmes and policies are now urgently needed to increase awareness of diabetes, reduce its risk factors, and improve diabetes diagnosis and control to reduce the public-health burden. In addition, these activities all need to involve a number of participating sectors, ranging from the health, education, social welfare and agricultural sectors to food industries and the mass media, among others.

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Author contributions

M.L. analyzed the data and wrote the manuscript. M.G.Z., G.X.H. and Y.S.C. planned the study. S.W.L., L.J.W. and Y.M.B. reviewed and

edited the manuscript. X.Y.Z. researched the data and reviewed the manuscript. H.B.G. contributed to the discussion, and reviewed and edited the manuscript. Y.N.L., Y.Y.J. and W.L.D. participated in the data analysis and edited the manuscript.

Disclosure of interest

The authors declare that they have no competing interest.

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