Trends in incidence of total or type 2 diabetes: systematic review

Dianna J Magliano,[1,2] Rakibul M Islam,[1,2] Elizabeth L M Barr,[1] Edward W Gregg,[3,4] Meda E Pavkov,[3] Jessica L Harding,[3] Maryam Tabesh,[1,2] Digsu N Koye,[1,2] Jonathan E Shaw,[1,2]

[1]Baker Heart and Diabetes Institute, Melbourne, VIC 3004, Australia
[2]School of Public Health and Preventive Medicine, Monash University, Melbourne, VIC 3004, Australia
[3]Centres for Diseases Control and Prevention, Division of Diabetes Translation, Atlanta, GA, USA
[4]School of Public Health, Epidemiology and Biostatistics, Imperial College London, London, UK

Correspondence to:
D J Magliano
dianna.magliano@baker.edu.au
(ORCID 0000-0002-9507-6096)

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ABSTRACT

OBJECTIVE

To assess what proportions of studies reported increasing, stable, or declining trends in the incidence of diagnosed diabetes.

DESIGN

Systematic review of studies reporting trends of diabetes incidence in adults from 1980 to 2017 according to PRISMA guidelines.

DATA SOURCES

Medline, Embase, CINAHL, and reference lists of relevant publications.

ELIGIBILITY CRITERIA

Studies of open population based cohorts, diabetes registries, and administrative and health insurance databases on secular trends in the incidence of total diabetes or type 2 diabetes in adults were included. Poisson regression was used to model data by age group and year.

RESULTS

Among the 22 833 screened abstracts, 47 studies were included, providing data on 121 separate sex specific or ethnicity specific populations; 42 (89%) of the included studies reported on diagnosed diabetes. In 1960-89, 36% (8/22) of the populations studied had increasing trends in incidence of diabetes, 55% (12/22) had stable trends, and 9% (2/22) had decreasing trends. In 1990-2005, diabetes incidence increased in 66% (33/50) of populations, was stable in 32% (16/50), and decreased in 2% (1/50). In 2006-14, increasing trends were reported in only 33% (11/33) of populations, whereas 30% (10/33) and 36% (12/33) had stable or declining incidence, respectively.

CONCLUSIONS

The incidence of clinically diagnosed diabetes has continued to rise in only a minority of populations studied since 2006, with over a third of populations having a fall in incidence in this time period. Preventive strategies could have contributed to the fall in diabetes incidence in recent years. Data are limited in low and middle income countries, where trends in diabetes incidence could be different.

SYSTEMATIC REVIEW REGISTRATION

Prospero CRD42018092287.

WHAT IS ALREADY KNOWN ON THIS TOPIC

Monitoring of the diabetes epidemic has mainly focused on reporting diabetes prevalence, which continues to rise; however, increasing prevalence is partly driven by improved medical treatment and declining mortality

Studies on diabetes incidence are scarce, but among those that exist, some report a fall or stabilisation of diabetes incidence;

Whether the proportion of studies reporting falling incidence has changed over time is not known

WHAT THIS STUDY ADDS

This systematic review of published data reporting diabetes incidence trends over time shows that in most countries with available data, incidence of diabetes (mainly diagnosed diabetes) increased from the 1990s to the mid-2000s, and has been stable or falling since

Preventive strategies and public health education and awareness campaigns could have contributed to this flattening of rates, suggesting that worldwide efforts to curb the diabetes epidemic over the past decade might have been effective

Published data were very limited in low and middle income countries, where trends in diabetes incidence might be different

Introduction

Over the past few decades, the prevalence of diabetes in developed and developing countries has risen substantially, making diabetes a key health priority globally.[1] Examination of trends in total burden of diabetes is an essential part of the monitoring of this health priority area, but, to date, it has consisted primarily of studies looking at diabetes prevalence.[1-5] Prevalence estimates suggest that the diabetes burden is still rising in most countries, and this is often interpreted as evidence of increasing risk in the population. However, selective incidence studies[6 7] and some accompanying risk factor data[8] suggest otherwise. Prevalence can be a crude and misleading metric of the trajectory of an epidemic, because increasing prevalence of a disease might be due to either increasing incidence or to improved survival. Furthermore, prevalence cannot be reliably used to study the effects of changes in population risk factors, because their effects are detected earlier with incidence trends than with prevalence trends, and incidence is not affected by changes in survival.

Incidence measures the proportion of people who develop diabetes over a period of time among the population at risk. It is the appropriate measure of population risk, and a valuable way of assessing whether public health campaigns for diabetes prevention are succeeding. While prevalence can rise simply because mortality falls, incidence of diagnosed diabetes is affected only by the risk of the population and the amount of screening undertaken. Changes in prevalence might be an inadequate guide to the effects of prevention activities, and could lead to the inappropriate rejection of effective interventions. It is only by measuring both incidence and prevalence that a better understanding of the extent of diabetes can be achieved.

Among existing diabetes incidence data, a few studies suggest that diabetes incidence could be falling despite rising or stable prevalence,[6 7 9] but not

all data are consistently showing the same trends. For example, studies from England and Wales (1994-98),[10] Portugal (1992-2015),[11] and Canada (1995-2007)[12] are reporting increases in diabetes incidence. To understand what is happening at a global level over time, a systematic approach to review all incidence trend data should be undertaken to study patterns and distributions of incidence trends by time, age, and sex. So far, no systematic reviews have reported on trends in the incidence of diabetes. Therefore, we conducted a systematic review of the literature reporting diabetes incidence trends.

Methods

Data sources and searches

We conducted a systematic review in accordance with PRISMA guidelines.[13] We searched Medline, Embase, and CINAHL from January 1980 to December 2017 without language restrictions. The full search strategy is available in supplementary table 1.

Study selection

Inclusion and exclusion criteria

Eligible studies needed to report diabetes incidence in two or more time periods. Study populations derived from open, population based cohort studies (that is, with ongoing recruitment over time), diabetes registries, or administrative or health insurance databases based mainly or wholly in primary care (electronic medical records, health insurance databases, or health maintenance organisations). We also included serial, cross sectional, population based studies where incidence was defined as a person reporting the development of diabetes in the 12 months before the survey. Studies were required to report on the incidence of either total diabetes or type 2 diabetes. We excluded studies reporting incidence restricted to select groups (eg, people with heart failure) and studies reporting only on children or youth.

Each title and abstract was screened by at least two authors (DJM, JES, DNK, JLH, and MT) and discrepancies were resolved by discussion. We aimed to avoid overlap of populations between studies. Therefore, if national data and regional data were available from the same country over the same time period, we only included the national data. If multiple publications used the same data source, over the same time period, we chose the publication that covered the longest time period.

Outcome measure

Our outcome was diabetes incidence using various methods of diabetes ascertainment including: blood glucose, glycated haemoglobin (HbA1c), linkage to drug treatment or reimbursement registries, clinical diagnosis by physicians, administrative data (ICD codes (international classification of diseases)), or self report. Several studies developed algorithms based on several of these elements to define diabetes. We categorised the definition of diabetes into one of five groups: clinical diagnosis, diabetes treatment, algorithm derived, glycaemia defined (blood glucose or HbA1c, with or without treatment), and self report.

Data extraction and quality of studies

We extracted crude and standardised incidence by year (including counts and denominators) and the reported pattern of the trends (increasing, decreasing, or stable, (that is, no statistically significant change)) in each time period as well as study and population characteristics. Age specific data were also extracted if available. Data reported only in graphs were extracted by DigitizeIt software (European Organisation for Nuclear Research, Germany). We assessed study quality using a modified Newcastle-Ottawa scale for assessing the risk of bias of cohort studies[14] (supplementary material).

Statistical methods

Data were reported as incidence density (per person year) or yearly rates (percentage per year). From every study, we extracted data from every subpopulation reported, such that a study reporting incidence in men and women separately contributed two populations to this analysis. If studies reported two different trends over different time periods, we considered these as two populations. Further, if the study was over 10 years in duration, we treated these as two separate time periods. To avoid double counting, when the data were reported in the total population as well as by sex and ethnic groups, we only included data once and prioritised ethnicity specific data over sex specific data.

We extracted the age specific incidence data reported for every individual calendar year. These data were then categorised into four age bands (<40, 40-54, 55-69, and ≥70), and were plotted against calendar year. In studies where counts and denominators were reported by smaller age groups than we used, we recalculated incidence across our specified larger age groups. If we found multiple age groups within any of our broader age groups, but with insufficient information to combine the data into a new category, only data from one age group were used. To limit overcrowding on plots, if data were available for men, women, and the total population, only total population data were plotted. Data from populations with high diabetes incidence such as Mauritians[15] and First Nation populations from Canada[16] were plotted separately to allow the examination of most of the data more easily on a common scale (supplementary material). Furthermore, studies reporting data before 1991 or populations with fewer than three data points were not plotted. We also categorised studies into European and non-European populations on the basis of the predominant ethnicity of the population in which they were conducted. Studies conducted in Israel, Canada, and the United States were assigned to the European category.

We took two approaches to analyse trends of diabetes incidence over time. Firstly, we allocated the reported trend (increasing, decreasing, or stable (that is, no statistically significant change)) of each population

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to the mid-point of each study's observational period, and then assigned this trend into one of five time periods (1960-79, 1980-89, 1990-99, 2000-05, and 2006-14). Where a test of significance of trends was not reported or when a time period was longer than 10 years, we performed Joinpoint trend analyses[17 18] to observe any significant trends in the data (assuming a constant standard deviation). Joinpoint Trend Analysis Software (version 4.5.0.1) uses permutation tests to identify points where linear trends change significantly in direction or in magnitude, and calculates an annual percentage change for each time period identified. In sensitivity analyses we also tested different cut points in the last two time periods.

The second approach was used to more accurately allocate trends to the prespecified time periods. Among the studies that reported raw counts of diabetes cases and denominators, we examined the association between calendar year and incidence, using Poisson models with the log person years as offset. The midpoints of age and calendar period were used as continuous covariates, and the effects of these were taken as linear functions. We analysed each study separately by prespecified time periods, and reported annual percentage change when the number of data points in the time period was at least four. For studies that did not provide raw data but did report a sufficient number of points, we analysed the relation between year and incidence using Joinpoint regression across the time periods specified above and reported annual percentage change. Analyses were conducted with Stata software version 14.0 (Stata Corporation, College Station, TX, USA), and Joinpoint (Joinpoint Desktop Software Version 4.5.0.1).[17 18]

Patient and public involvement

No patients or members of the public were involved in setting the research question or the outcome measures for this study. No patients were asked to advise on interpretation or writing up of results. We intend to disseminate this research through press releases and at research meetings.

Results

We found 22 833 unique abstracts from 1 January 1980 to the end of 2017. Among these, 80 described trends of diabetes incidence, of which 47 met all inclusion criteria. Articles describing trends were excluded for the following reasons: duplicated data (n=21), closed cohorts (n=5), populations included youth only (n=1), occupational cohorts (n=2), or no usable data presented (n=4; fig 1).

Table 1 and supplementary material table 2 describe the characteristics of the included studies. Only 19% (9/47) of studies were from predominantly non-Europid populations and 4% (2/47) of studies were from low or middle income countries (China[25] and Mauritius[15]). Administrative datasets, health insurance data, registry data, survey data, and cohort studies accounted for 38% (n=18), 21% (n=10), 19% (n=9), 11% (n=5), and 11% (n=5) of the 47 data sources, respectively. Among the 47 studies, diabetes was defined by a clinical diagnosis, diabetes treatment (via linkage to drug treatment registers), an algorithm, blood glucose, and self report in 28% (n=13), 9% (n=4), 47% (n=22), 11% (n=5), and 6% (n=3) of studies, respectively. Sample sizes of the populations were greater than 10 000 in every year in 85% (n=40) of the studies, and greater than 130 000 per year in 70% (n=33) of the studies. A total of 62% (n=29) of the 47 included studies exclusively reported on type 2 diabetes, and 38% (n=18) reported on total diabetes.

Trends of diabetes incidence

Among the 47 studies, 16 provided information on incidence by age group. Of these 16 studies, 14 were plotted in figure 2, with those from high incidence countries plotted in supplementary figure 1. In these figures, incidence in most studies increased progressively until the mid-2000s in all age groups. Thereafter, most studies showed a stable or decreasing trend, apart from studies in Denmark[26 27] and Germany[31] and in a US health insurance population[9] where the incidence inflected upwards in the later years for some age groups.

Using the first approach to analyse trends of diabetes incidence over time, we separated the data into populations based on sex and ethnicity, and allocated a time period to each population, generating 105 populations for analysis. Seventy four and 31 populations were predominantly Europid and non-Europid, respectively. Table 2 and table 3 show the reported trend for each population. Table 4 summarises the findings in table 2 and table 3, and shows that the proportion of populations reporting increasing trends peaked in 1990-99 and fell progressively in the two later time periods. Between 1960 and 1989, 36% (8/22) of the populations studied had increasing trends in incidence of diabetes, 55% (12/22) had stable trends, and 9% (2/22) had decreasing trends. In 1990-2005, diabetes incidence increased in 66% (33/50) of populations, was stable in 32% (16/50), and decreased in 2% (1/50). In 2006-14, increasing trends were reported in 33% (11/33) of populations, whereas 30% (10/33) and 36% (12/33) had stable or declining incidence, respectively.

Populations that reported a decrease in incidence after 2005 came from the US,[6 9] Israel,[34] Switzerland,[46] Hong Kong,[32] Sweden,[43] and Korea.[36] Populations reporting increasing incidence after 2005 included Portugal,[11] Denmark,[26 27] and Germany,[31] while populations from Canada,[19] Italy,[35] Scotland,[40] Norway,[39] US (non-Hispanic white),[56] and the United Kingdom[50] showed stable incidence. For two studies (16 populations),[16 29] we could not determine a direction of a trend (increasing, decreasing, or stable), because they showed three phases of change with the trend of the middle phase differing from the trend of the first and last phase. Across the total time period, we observed a higher proportion of populations reporting stable or decreasing trends in predominantly Europid than in non-Europid populations (52% *v* 41%).

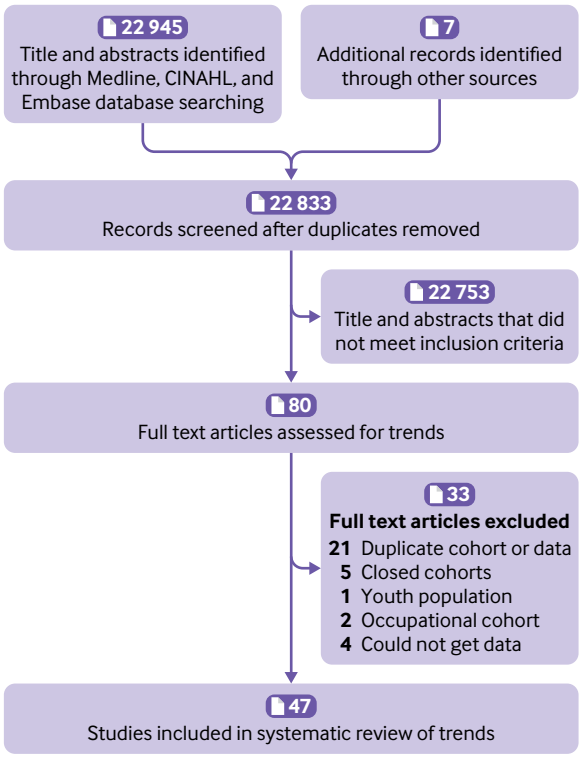

Fig 1 | Flowchart of study selection

Using the second approach to analyse trends of diabetes incidence over time, we modelled 21 studies (62 populations) that reported diabetes counts and denominators specifically within each time period (table 5). The percentage of populations with a decreased or stable incidence was highest in 1980-89 (88%; 7/8), but this proportion was based on only eight populations in three studies. From 1990 onwards, the percentage with decreasing or stable incidence increased progressively, reaching 83% (19/23) of populations in 2006-14. Eight studies (21 populations) that were analysed by Joinpoint had no data on counts or denominators (supplementary table 3). When these data were considered with the data in table 5, the percentage of populations in 2006-14 with decreasing or stable incidence fell to 70% (19/27), but this proportion was still the highest of all the time periods, whereas the percentage for 1990-99 remained the lowest at 31% (5/16).

In a sensitivity analysis, we tested whether our selection of time periods was driving our results. When we defined the final time periods to be 2000-07 and 2008-14, our results were not altered, with 66% (21/32) of the populations in the last time period showing decreasing or stable trends. We also repeated the analysis in table 4 and excluded cohort studies and surveys, and found that the results were not materially

Table 1 | Characteristics of 47 included studies reporting on diabetes incidence trends, by country

Author, year	Years reported	Country	Origin of data	Type of data	Diabetes definition	Age range
CCDSS et al 2017[19]	2000-11	Canada	CCDSS (administrative data)	Administrative	Administrative algorithm	≥0
Dyck et al 2010[16]	1980-2005	Canada	Ministry of Health's insurance registry	Administrative	Administrative algorithm	≥20
Oster et al 2011[12]	1995-2007	Canada, Alberta	Provincial administrative health records	Administrative	Administrative algorithm	≥20
Blanchard et al 1996*[20]	1986-91	Canada, Manitoba	Manitoba Health Insurance, diabetes database	Health insurance	Administrative algorithm	≥25
Green et al 2003*[21]	1989, 1998†	Canada, Manitoba	Manitoba Health Insurance, diabetes database	Health insurance	Administrative algorithm	≥20
Alangh et al 2013[22]	1996, 2001, 2003, 2005†	Canada, Ontario	Population health surveys linked to registry	Survey	Clinical diagnosis	≥30
Lipscombe et al 2007[23]	1997-2003	Canada, Ontario	Population based diabetes database	Administrative	Administrative algorithm	≥20
Horn et al 2007[24]	1986-2003	Canada, Quebec	KHMC diabetes registry	Registry	Clinical diagnosis	≥18
Liu et al 2007[25]	1999-2005	China, Harbin	Administrative health database	Administrative	Clinical diagnosis	≥0
Carstensen et al 2008*[26]	1995-2006	Denmark	National diabetes register	Registry	Administrative algorithm	≥0 ≥0
Green et al 2015*[27]	2000-11	Denmark	National diabetes register	Registry	Administrative algorithm	
Abouzeid et al 2015[28]	1970s, 1980s, 1990s†	Finland	Finnrisk surveys linked to reimbursement database	Survey	Diabetes treatment	30-59
Laakso et al 1991[29]	1970-87	Finland	Medication database	Registry	Diabetes treatment	≥30
Michaeli et al 1993[30]	1940-89	Germany, East	National diabetes register	Registry	Clinical diagnosis	≥0
Boehme et al 2015[31]	2007-10	Germany, southwestern	Claims data AOK Baden, Wuerttemberg	Health insurance	Administrative algorithm	≥0
Quan et al 2017[32]	2007-14	Hong Kong, China	Hospital Authority clinical management system	Administrative	Administrative algorithm	≥20
Vilbergsson et al 1997[33]	1968-71, 1972-75, 1976-79, 1980-85†	Iceland, Reykjavik	Reykjavik study	Cohort studies	Glucose (FBG, OGTT) plus treatment	34-79
Karpati et al 2014[34]	2004-12	Israel	Clalit health services	Health insurance	Administrative algorithm	›26
Monesi et al 2011[35]	2000-07	Italy, Lombardy	Administrative health database	Administrative	Administrative algorithm	≥0
Song et al 2016[36]	2004-12	Korea	Korean national data health insurance	Health insurance	Administrative algorithm	≥0
Soderberg et al 2004[15]	1987-92, 1992-98†	Mauritius	Non communicable disease survey	Cohort studies	Glucose (FBG, OGTT) plus treatment	20-79
Dowse et al 1991[37]	1975/76-82, 1982-87†	Nauru	Non communicable disease survey	Survey	Glucose (FBG, OGTT) plus treatment	≥20
Ruwaard et al 1996[38]	1980-83, 1990-92†	Netherlands	Dutch Sentinel Practice network	Administrative	Clinical diagnosis	≥0
Strom et al 2014[39]	2006-11	Norway	Norwegian prescription database	Administrative	Diabetes treatment	≥0

Table 1 | Continued

Author, year	Years reported	Country	Origin of data	Type of data	Diabetes definition	Age range
de Sousa-Uva et al 2016[11]	1992-2015	Portugal	General Practice Sentinel network	Administrative	Clinical diagnosis	≥0
Evans et al 2007[40]	1993-2004	Scotland	DARTS clinical system	Administrative	Administrative algorithm	>35
Read et al 2016[41]	2004-13	Scotland	Diabetes register	Registry	Clinical diagnosis	40-89
Berger et al 1999[42]	1991-95	Sweden	Skaraborg Swedish diabetes registry	Registry	Clinical diagnosis	≥0
Jansson et al 2015[43]	2006-12	Sweden	Data from national Swedish registers	Registry	Diabetes treatment	≥0
Jansson et al 2007[44]	1972-2001	Sweden, Laxa	Diabetes register in primary care network	Administrative	Clinical diagnosis	≥0
Ringborg et al 2008[45]	1996-2003	Sweden, Uppsala	RECAP-DM (26 primary healthcare providers)	Administrative	Administrative algorithm	>30
Huber et al 2014[46]	2007, 2011†	Switzerland	Switzerland healthcare claims data	Health insurance	Administrative algorithm	≥19
Lin et al 2013[47]	2000-07	Taiwan	National insurance research database	Health insurance	Administrative algorithm	≥20
Tseng et al 2006[48]	1992-96	Taiwan	National insurance research database	Health insurance	Administrative algorithm	≥0
Holden et al 2013*[49]	1991-2010	UK	Clinical Practice Research Datalink	Administrative	Clinical diagnosis	≥0
Zghebi et al 2017*[50]	2004-14	UK	Clinical Practice Research Datalink	Administrative	Clinical diagnosis	≥16
Abraham et al 2015[8]	1970s, 1980s, 1990s, 2000s†	US	FHS, FOS, population based, biennial exams	Cohort study	Glucose (FBG) plus treatment	40-55
Akushevich et al 2013[51]	1993-2005	US	Seer Medicare NLTCS Medicare	Administrative	Clinical diagnosis	>65
Burke et al 2002[52]	1970-74, 1975-79, 1990-84, 1985-89, 1990-94†	US	Rochester epidemiology project	Administrative	Administrative algorithm	≥30
CDC et al 2008[53]	1995-97, 2005-07†	US	BFRSS	Survey	Self report	≥18
Geiss et al 2014[6]	1980-2012	US	NHIS	Survey	Self report	20-79
McBean et al 2004[54]	1994-2001	US	Medicare database	Administrative	Administrative algorithm	≥65
Narayanan et al 2010[55]	1986-90, 1991-98, 1999-2001, 2001-06†	US	Alaska Native diabetes registry	Registry	Clinical diagnosis	≥0
Nichols et al 2015[56]	2006-11	US	Multicentre consortium SUPREME-DM	Health insurance	Administrative algorithm	≥20
Tabaei et al 2012[57]	2002, 2004, 2008†	US	New York Community Health Survey	Cohort study	Self report	≥18
Weng et al 2016[9]	2007, 2012†	US	Truven Health MarketScan	Health insurance	Administrative algorithm	≥18
Pavkov et al 2007[58]	1965-77, 1978-90, 1991-2003†‡	US, Pima	Cohort study with biennial exams	Cohort study	Glucose (FBG, OGTT) plus treatment	≥5

BRFSS=Behavioural Risk Factor Surveillance System; CCDSS=Canadian chronic disease surveillance system; CDC=US Centre for Disease Control and Prevention; DARTS=Diabetes Audit and Research in Tayside Scotland; FBG=fasting blood glucose; FHS=Framingham Heart Study; FOS=Framingham Offspring Study; KMHC=Kateri Memorial Hospital Centre; NHIS=National Health Interview Survey; NLTCS=National Long Term Care Survey; OGTT=oral glucose tolerance test; RECAP-DM= Real-Life Effectiveness and Care Patterns in Diabetes Management; SUPREME-DM=Surveillance, Prevention and Management of Diabetes Mellitus study.
*Studies used the same country or region specific data source; authors used the same database but reported incidence for different time periods.
†Studies did not measure incidence in continuous years.
‡Sex specific incidence was not reported in the paper, but described in the text.

altered, with 65% (20/31) of populations in the last time period (from 2006 onwards) showing decreasing or stable incidence of diabetes.

Quality of studies

The median score for study quality was 10 (interquartile range 8-11; supplementary table 4). We repeated the analyses reported in table 4 after excluding studies that had quality scores in the lowest quarter, and observed similar results to the main findings. For example, in 1960-89, 67% (10/15) of populations reported stable or decreasing incidence, while in the final time period, 67% (18/27) of populations reported stable or decreasing incidence of diagnosed diabetes.

Discussion

Principal findings

In this systematic review of population based studies on diabetes incidence, we show evidence that the incidence of diagnosed diabetes increased in most populations from the 1960s to the early 2000s, after which a pattern emerged of levelling trends in 30% and declining trends in 36% of the reported populations. Although the lack of data for non-Europid populations leaves global trends in incidence unclear, these findings suggest that trends in the diabetes epidemic in some high income countries have turned in a more encouraging direction compared with previous decades. It is important to note that these results apply predominantly to type 2 diabetes, as even though many studies did not accurately define diabetes type, the incidence of type 2 diabetes in adults is an order of magnitude greater than that of type 1 diabetes.

The countries that showed stable or decreasing trends in the last time period were from Europe and east Asia, with no obvious clustering or commonalities. For the countries showing decreasing or stable diabetes trends, if the prevalence data were used to understand the diabetes epidemic in that country, a different message would be obtained. For example, national data from Korea showed that the prevalence of diabetes increased from 2000 to 2010.[59] Similarly in Sweden, the prevalence of pharmacologically treated diabetes increased moderately from 2006 to 2014.[43] In

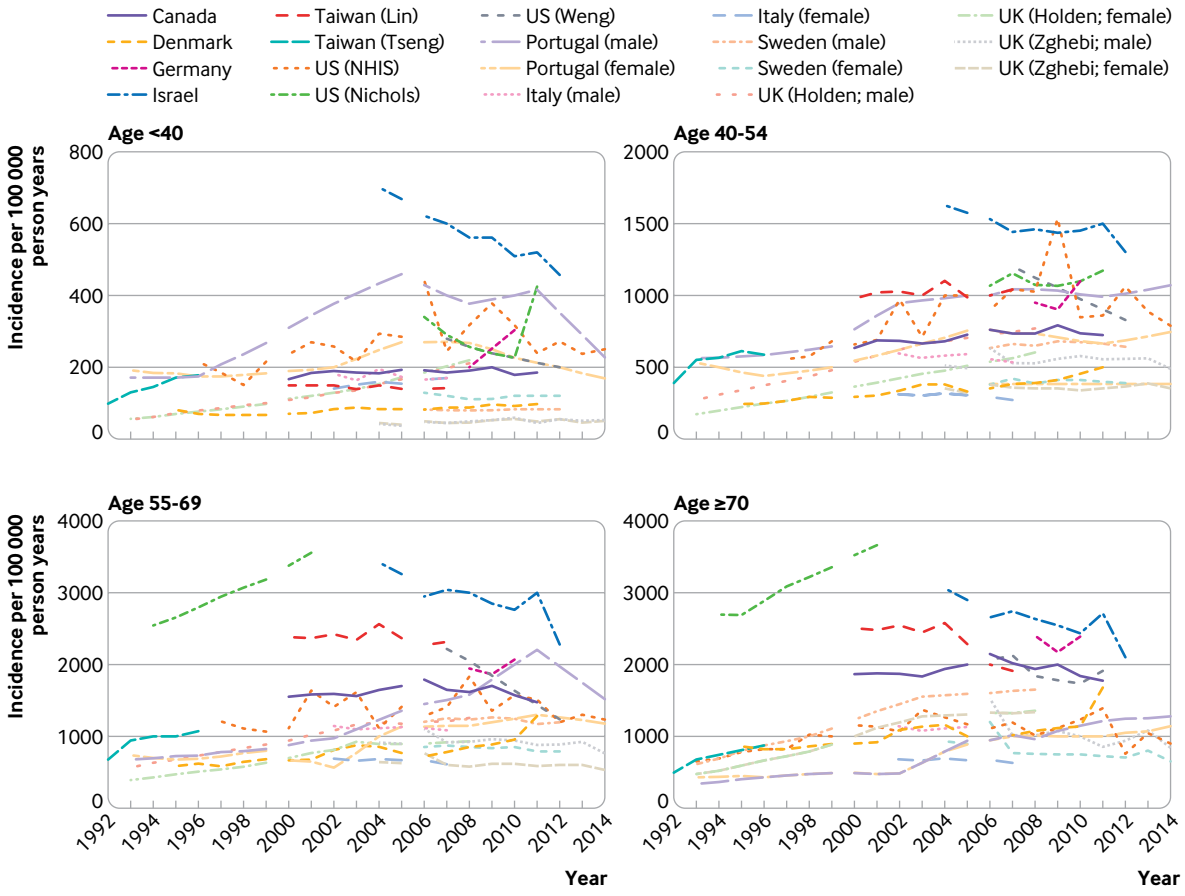

Fig 2 | Incidence of diabetes over time for populations aged under 40, 40-54, 55-69, and 70 or more, among studies reporting age specific data. Only populations with at least three points were plotted. NHIS=National Health Interview Survey

the US, the prevalence of diabetes reached a plateau when incidence began to decrease. However, we lacked incidence data from many areas of the world where the most steady and substantial increases in prevalence have been reported, including the Pacific Islands, Middle East, and south Asia. Large increases in incidence could still be occurring in these areas. The lack of incidence data for much of the world, combined with the common observation of discordance between incidence and prevalence rates where such data exist, both underscore the importance of using incidence data to understand the direction of the diabetes epidemic.

Incidence could be starting to fall for several reasons. Firstly, we might be starting to benefit from prevention activities of type 2 diabetes, including increased awareness, education, and risk factor modification. These activities have involved both targeted prevention among high risk individuals, similar to that conducted in the Diabetes Prevention study[60] and Diabetes Prevention Programme[61 62] in many countries,[63] and less intensive interventions with broader reach such as telephone counselling in the general community.[64-67] Secondly, health awareness and education programmes have also been implemented in schools and work places, and many changes to the physical environment, such as the introduction of bike tracks and exercise parks, have occurred.[68] Thirdly, favourable trends in selected risk factors of type 2 diabetes in some countries provide indirect evidence of positive changes to reduce diabetes incidence. Finally, in the US, there is some evidence in recent years of improved diets and related behaviours, which include reductions in intake of sugar sweetened beverages[69] and fat,[70] small declines in overall energy intake, and declines in some food purchases.[8 71]

Similar reduction in consumptions of sugar sweetened beverages have occurred in Norway[72] and Australia[73] and fast food intake has decreased in Korea.[74] Some of these changes could be linked to a fall in diabetes incidence. Some places such as Scotland[75] have also had a plateauing of obesity prevalence, but this is not universal. In the US, despite earlier studies suggesting that the rate of increase in obesity might be slowing down,[76 77] more recent data show a small increase.[78 79] While some evidence supports the hypothesis that these prevention activities for type 2 diabetes and an improved environment could trigger sufficient behaviour change to have an effect on diabetes incidence, other data, such as the continuing rising obesity prevalence in the US,[79] casts some doubt over the explanations underpinning our findings on diabetes incidence trends.

Other factors might have also influenced reported diabetes incidence. Only 11% (n=5) of the studies reported here screened for undiagnosed diabetes, and therefore trends could have been influenced by

Table 2 | Summary of patterns of diabetes incidence trends based on analyses reported in publications in 1960-99

First author, year	Years included (range)	Mid-point	Country	Predominant ethnicity	Incidence trends (increasing, stable, or decreasing)		
					Men	Women	Total
1960-79							
Michaelis et al 1993*[30]	1960-69	1965	Germany	Europid			Increase
Michaelis et al 1993*[30]	1970-79	1975	Germany	Europid			Increase
Jansson et al 2007[44]	1972-79	1976	Sweden	Europid	Stable	Stable	
Vilbergsson et al 1997[33]	1968-85	1977	Iceland	Europid	Stable	Stable	
Burke et al 2002[52]	1970-82	1976	US	Europid	Increase	Increase	
Pavkov et al 2007[58]	1971-84	1978	US	Non-Europid (Pima)			Stable
1980-89							
Abouzeid et al 2015[28]	1975-85	1980	Finland	Europid	Increase	Stable	
Abraham et al 2015[7]	1970-89	1980	US	Europid			Stable
Dowse et al 1991[37]	1979-85	1982	Nauru	Non-Europid			Stable
Abraham et al 2015[7]	1970-97	1984	US	Europid			Increase
Michaelis et al 1993*[30]	1980-89	1985	Germany	Europid			Stable
Jansson et al 2007[44]	1980-89	1985	Sweden	Europid	Stable	Stable	
Geiss et al 2014[6]	1980-89	1985	US	Europid	Increase	Stable	
Ruwaard et al 1996[38]	1980-92	1986	Netherlands	Europid			Increase
Blanchard et al 1996[20]	1986-91	1989	Canada	Europid	Decrease	Decrease	
1990-99							
Horn et al 2007†[24]	1986-94	1990	Canada	Non-Europid (First Nation)			Decrease
Abouzeid et al 2015[28]	1985-95	1990	Finland	Europid	Increase	Stable	
Burke et al 2002[52]	1987-92	1990	US	Europid	Stable	Stable	
Pavkov et al 2007[58]	1984-97	1991	US	Non-Europid (Pima)			Stable
Soderberg et al 2004[15]	1987-98	1993	Mauritius	Non -Europid	Stable	Increase	
Berger et al 1999[42]	1991-95	1993	Sweden	Europid			Stable
Tseng et al 2006[48]	1992-96	1994	Taiwan	Non-Europid (Taiwan)	Increase	Increase	
Jansson et al 2007[44]	1990-99	1995	Sweden	Europid	Stable	Stable	
Holden et al 2013[49]	1991-2000	1995	UK	Europid	Increase	Increase	
Geiss et al 2014[6]	1990-2000	1995	US	Europid	Increase	Increase	
Cartensen et al 2008‡[26]	1989-2003	1996	Denmark	Europid	Increase	Increase	
Narayanan et al 2010[55]	1986-2006	1996	US, Alaska	Non-Europid (Indian)			Increase
Narayanan et al 2010[55]	1986-2006	1996	US, Alaska	Non-Europid (Aleut)			Increase
Narayanan et al 2010[55]	1986-2006	1996	US, Alaska	Non-Europid (Eskimo)			Increase
de Sousa-Uva et al 2016[11]	1992-2003	1998	Portugal	Europid	Increase	Increase	
McBean et al 2004[54]	1994-2001	1998	US	Europid			Increase
McBean et al 2004[54]	1994-2001	1998	US	Non-Europid (White)			Increase
McBean et al 2004[54]	1994-2001	1998	US	Non-Europid (Black)			Increase
McBean et al 2004[54]	1994-2001	1998	US	Non-Europid (Hispanic)			Increase
Horn et al 2007†[24]	1994-2003	1999	Canada	Non-Europid (First Nation)			Stable
Evans et al 2007[40]	1993-2004	1999	UK	Europid	Increase	Increase	
Akushevich et al 2013[51]	1992-2005	1999	US	Europid			Increase

Empty cells in the table imply that the study did not report data through that decade.
*First period of data from 1945-60 not included.
†Only total population data was used from Horn et al,[24] because sex specific data were based on small numbers.
‡Data from Denmark were extracted from Carstensen et al[26] and Green et al.[27] These authors used the same database but reported incidence for different time periods.

secular changes in diagnostic behaviour. In 1997, the threshold for fasting plasma glucose for diagnosis of diabetes was reduced from 7.8 to 7.0 mmol/L, which could increase diagnosis of new cases of type 2 diabetes. In 2009-10, HbA1c was then introduced as an alternative way to diagnose diabetes.[80] Evidence from some studies suggests that the HbA1c diagnostic threshold detects fewer people with diabetes than do the thresholds for fasting plasma blood glucose,[80 81] potentially leading to a lowering of incidence estimates. However, across multiple studies, prevalence estimates based on fasting plasma glucose only versus HbA1c definitions are similar.[82] Furthermore, because HbA1c can be measured in the non-fasting state (unlike the fasting blood glucose or oral glucose tolerance test), the number of people who actually undergo diagnostic testing could be higher with HbA1c. Nichols and colleagues[56] reported that among seven million insured US adults, despite a shift towards HbA1c as the diagnostic test in 2010, the incidence of diabetes did not change from 2010 to 2011.

Another potential explanation for declining or stable diabetes incidence after the mid-2000s is a reduction in the pool of undiagnosed diabetes[83] through the intensification of diagnostic and screening activities[83 84] and changing diagnostic criteria during the previous decade.[80] Data from Read and colleagues provide some evidence to support this notion.[41]

Among the included studies, two studies specifically examined clinical screening patterns in parallel with incidence trends. These studies reported that the proportion of the population screened for diabetes increased over time, and the incidence of diabetes remained stable[56] or fell.[34] While the Karpati study[34] combined data for glucose testing with HbA1c testing, the study by Nichols and colleagues[56] separated the two, and showed that both glucose testing and HbA1c testing increased over time. A third study, in Korea,[36]

Table 3 | Summary of patterns of diabetes incidence trends based on analyses reported in publications in 2000-14

First author, year	Years reported (range)	Mid-point	Country	Predominant ethnicity	Incidence trends (increasing, stable, or decreasing)		
					Men	Women	Total
2000-05							
Lipscombe et al 2007[23]	1997-2003	2000	Canada	Europid			Increase
Ringborg et al 2008[45]	1996-2003	2000	Sweden	Europid			Stable
Abraham et al 2015[7]	1990-2009	2000	US	Europid			Stable
Oster et al 2011[12]	1995-2007	2001	Canada	Europid	Increase	Increase	
Oster et al 2011[12]	1995-2007	2001	Canada	Non-Europid (indigenous)	Increase	Stable	
CDC et al 2008[53]	1995-2007	2001	US	Europid			Increase
Liu et al 2007[25]	1999-2005	2002	China	Non-Europid (China)			Increase
Monesi et al 2011[35]	2000-07	2004	Italy	Europid			Stable
Lin et al 2013[47]	2000-07	2004	Taiwan	Non-Europid (Taiwan)	Stable	Stable	
CCDSS et al 2017[19]	2000-06	2004	Canada	Europid	Increase	Increase	
Cartensen et al 2008*[26 27]	2004-06	2005	Denmark	Europid			Increase
Holden et al 2013*[49]	2001-10	2005	UK	Europid	Increase	Increase	
Tabaei et al 2012[57]	2002-08	2005	US	Europid			Stable
2006-14							
Song et al 2016[36]	2004-09	2007	Korea	Non-Europid (Korea)			Decrease
Karpati et al 2014[34]	2004-12	2008	Israel	Europid			Decrease
CCDSS et al 2017[19]	2007-11	2009	Canada	Europid	Stable	Stable	
Boehme et al 2015[31]	2008-10	2009	Germany	Europid	Increase	Increase	
Strom et al 2014[39]	2006-11	2009	Norway	Europid	Stable	Decrease	
de Sousa-Uva et al 2016[11]	2004-15	2009	Portugal	Europid	Increase	Increase	
Read et al 2016[41]	2004-13	2009	Scotland	Europid	Stable	Stable	
Huber et al 2014[46]	2007-11	2009	Switzerland	Europid	Decrease	Decrease	
Zghebi et al 2017*[50]	2004-14	2009	UK	Europid	Stable	Stable	
Nichols et al 2015[56]	2006-11	2009	US	Europid (Non-Hispanic white)	Stable	Stable	
Nichols et al 2015[56]	2006-11	2009	US	Non-Europid (black)			Increase
Nichols et al 2015[56]	2006-11	2009	US	Non-Europid (Hispanic)			Increase
Nichols et al 2015[56]	2006-11	2009	US	Non-Europid (Asian)			Increase
Nichols et al 2015[56]	2006-11	2009	US	Non-Europid (Native American)			Increase
Nichols et al 2015[56]	2006-11	2009	US	Non-Europid (Hawaiian/ Pacific)			Increase
Green et al 2015*[27]	2007-11	2009	Denmark	Europid	Increase	Increase	
Jansson et al 2015[43]	2006-13	2010	Sweden	Europid	Decrease	Decrease	
Geiss et al 2014[6]	2008-12	2010	US	Europid	Decrease	Decrease	
Weng et al 2016[9]	2007-12	2010	US	Europid			Decrease
Quan et al 2017[32]	2007-14	2011	Hong Kong, China	Non-Europid (Hong Kong)	Decrease	Decrease	
Song et al 2016[36]	2009-12	2011	Korea	Non-Europid (Korea)			Stable

Empty cells imply that the study did not report data through that decade. CDC=US Centre for Disease Control and Prevention; CCDSS=Canadian chronic disease surveillance system (published online only).
*These authors used the same country specific database but reported incidence for different time periods.

also noted that the incidence of diabetes decreased in the setting of an increase in the uptake of the national health screening programme. Despite the introduction of HbA1c for diagnosis of diabetes by the World Health Organization, this practice has not been adopted everywhere. For example, neither Scotland nor Hong Kong have introduced the use of HbA1c for screening or diagnosis of diabetes, and studies in these areas showed a levelling of diabetes incidence trends and decreasing trends, respectively.

Our findings appear to contrast with data showing increasing global prevalence of diabetes.[13] However, increasing prevalence could be influenced by improved survival of people with diabetes, because this increases the length of time that each individual remains within the diabetes population. As is shown in several studies in this review,[23 41] mortality from diabetes and incidence of diabetes might both be falling but as long as mortality is lower than incidence, prevalence will rise. Therefore, we argue that prevalence alone is an insufficient measure to track the epidemic of diabetes and other non-communicable diseases.

Table 4 | Summary of incidence trends over time of total or type 2 diabetes

Study years	No of populations	Distribution of populations (No (%))		
		Increased	Stable	Decreased
1960-79	9	4 (44)	5 (56)	0
1980-89	13	4 (31)	7 (54)	2 (15)
1990-99	32	22 (69)	9 (28)	1 (3)
2000-05	18	11 (61)	7 (39)	0
2006-14	33	11 (33)	10 (30)	12 (36)
Total	105	—	—	—

Strengths and weaknesses of this study

A key strength of this work was the systematic approach and robust methodology to describe trends in diagnosed diabetes incidence. We also presented the reported trends allocated to approximate time periods, as well as conducting our own regression within exact time periods. The following limitations should also be considered. Firstly, we did not formally search the grey literature, because a preliminary grey literature search revealed only low quality studies,

Table 5 | Annual percentage change in diabetes incidence in men (M), women (W), or total population (T) among studies that provided counts and denominators, by time period

Author, year	Population	Country	Annual percentage change (%) in incidence, P value				
			1970-79	1980-89	1990-99	2000-05	2006-14
CCDSS et al 2017[19] Canada	M	Canada	—	—	—	0.8, 0.001	−2.6, 0.001
CCDSS et al 2017[19] Canada	F	Canada	—	—	—	1.8, <0.001	−2.8, <0.001
Dyck et al 2010[16] (First Nation)	M	Canada	—	2.2, 0.06	4.8, <0.001	−0.3, 0.86	—
Dyck et al 2010[16] (First Nation)	F	Canada	—	−2.4, 0.02	−0.1, 0.90	−6.03, <0.001	—
Dyck et al 2010[16] (Non-First Nation)	M	Canada	—	−1.5, <0.001	3.6, <0.001	−1.4, 0.006	—
Dyck et al 2010[16] (Non-First Nation)	F	Canada	—	−2.5, <0.001	3.1, <0.001	−1.0, 0.06	—
Horn et al 2007[24]	M	Canada	—	—	−7.5, 0.08	—	—
Horn et al 2007[24]	F	Canada	—	—	−7.5, 0.01	—	—
Liu et al 2007[25]	T	China				11.0, <0.001	
Boehme et al 2015[31]	M	Germany	—	—	—	—	1.6, <0.001
Boehme et al 2015[31]	F	Germany	—	—	—	—	2.9, <0.001
Quan et al 2017[32]	M	Hong Kong, China	—	—	—	—	−1.70, <0.001
Quan et al 2017[32]	F	Hong Kong, China	—	—	—	—	−1.27, <0.001
Karpati et al 2014[34]	T	Israel	—	—	—	−5.3, <0.001	−3.2, <0.001
Song et al 2016[36]	M	Korea	—	—	—	11.3, <0.001	1.3, <0.001
Song et al 2016[36]	F	Korea	—	—	—	17.2, <0.001	−0.9, <0.001
Strom et al 2014[39]	M	Norway	—	—	—	—	−0.5, 0.7
Strom et al 2014[39]	F	Norway	—	—	—	—	−1.5, 0.1
Read et al 2016[41]	M	Scotland	—	—	—	−5.5, <0.001	−0.03, 0.86
Read et al 2016[41]	F	Scotland	—	—	—	−9.2, <0.001	−0.8, <0.001
Jansson et al 2015[43]	M	Sweden	—	—	—	—	−0.3, <0.001
Jansson et al 2015[43]	F	Sweden	—	—	—	—	−0.9, <0.001
Ringborg et al 2008[45]	T	Sweden	—	—	−3.8, 0.01	−4.8, 0.001	—
Huber et al 2014[46]	M	Switzerland	—	—	—	—	−3.6, 0.001
Huber et al 2004[46]	F	Switzerland	—	—	—	—	−3.5, 0.02
Lin et al 2013[47]	T	Taiwan	—	—	—	−2.4, <0.001	3.9, <0.001
Tseng et al 2006[48]	M	Taiwan	—	—	15.4, <0.001	—	—
Tseng et al 2006[48]	F	Taiwan	—	—	8.1, <0.001	—	—
Zghebi et al 2017[50]	M	UK	—	—	—	—	−4.1, 0.01
Zghebi et al 2017[50]	F	UK	—	—	—	—	−3.0, <0.001
Burke et al 2002[52]	M	US	5.0, 0.04	5.0, 0.02	—	—	—
Burke et al 2002[52]	F	US	−5.3, <0.02	2.2, 0.29	—	—	—
McBean et al 2004[54]	T	US	—	—	5.0 <0.001	—	—
Nichols et al 2015[56]	T	US	—	—	—	—	−0.04, 0.91
Geiss et al 2014*[6]	M	US	—	0.5, 0.81	13.6, <0.001	1.6, 0.5	−4.1, <0.001
Geiss et al 2014*[6]	F	US	—	1.8, 0.32	9.4, <0.001	4.7, 0.01	−1.5, 0.07
Weng et al 2016[9]	T	US	—	—	—	−8.0, <0.001	—
Summary: Percentage (%) of populations that showed increasing incidence trends over time period	—	—	50	12	66	31	17
Summary: Percentage (%) of populations that showed decreasing or stable incidence trends over time period	—	—	50	88	33	69	83

CCDSS=Canadian chronic disease surveillance system (published online only).
*These data were supplemented using additional National Health Interview Survey data held by the US Centers for Disease Control and Prevention.

with inadequate methodological detail to provide confidence in any observed incidence trends, and thus review could be subject to publication bias. Secondly, we were not able to source age or sex specific data on all populations. Thirdly, it was not possible to adjust for different methods of diabetes diagnosis or ascertain trends by different definitions of diabetes. Fourthly, most data sources reported only on clinically diagnosed diabetes and so were subject to influence from diagnostic behaviour and coding practices. Fifthly, study type changed over time, with large administrative datasets becoming more common and cohort studies becoming less common over time. Nevertheless, the size and absence of volunteer bias in administrative datasets likely make them less biased. Finally, data were limited in low and middle income countries.

Conclusions and unanswered questions

This systematic review shows that in most countries for which data are available, the incidence of diagnosed diabetes was rising from the 1990s to the mid-2000s, but has been stable or falling since. Preventive strategies and public health education and awareness campaigns could have contributed to this recent trend. Data are limited in low and middle income countries where trends in diabetes incidence might be different. Improvement of the collection, availability, and analysis of incidence data will be important to effectively monitor the epidemic and guide prevention efforts into the future.

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the US Centers for Disease Control and Prevention (CDC).

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DJM also screened abstracts. ELMB applied the quality criteria to the selected articles. RMI extracted data, applied quality criteria to selected articles, and contributed to preparing the manuscript. DJM conceived the project, screened abstracts, extracted the data, analysed the data, and wrote the manuscript. JES, MEP, and EWG conceived the project, edited the manuscript, and provided intellectual input throughout the process. The funder of the study (CDC) was part of the study group and contributed to data collection, data analysis, data interpretation, and writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication. DJM is guarantor. 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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Data sharing: Data are available from the corresponding author (dianna.magliano@baker.edu.au).

The lead author affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

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Web appendix: Supplementary material
Web appendix: Visual summary