# Edinburgh Research Explorer

# Lifetime risk, life expectancy, and years of life lost to type 2 diabetes

**Lifetime risk, life expectancy, and years of life lost to type 2 diabetes: a multi-national population-based study of 23 high-income jurisdictions**

Dunya Tomic, MBBS(Hons),[1, 2] Jedidiah I Morton, BSc(Hons),[1, 2, 3] Lei Chen, PhD,[1] Agus Salim, PhD[1, 4, 5] Prof Edward W Gregg, PhD,[6] Meda E Pavkov, MD,[7] Martti Arffman, MSc,[8] Prof Ran Balicer, MD,[9] Marta Baviera, PharmD,[10] Elise Boersma-van Dam, MSc,[11] Ralph Brinks, PhD,[12, 13] Bendix Carstensen, MSc,[14] Prof Juliana C N Chan, MD,[15] Yiling J Cheng, PhD,[7] Sandrine Fosse-Edorh, PhD,[16] Sonsoles Fuentes, MPH,[16] Hélène Gardiner, MPH,[17] Hanne L Gulseth, MD,[18] Prof Romualdas Gurevicius, PhD,[19, 20] Prof Kyoung Hwa Ha, PhD,[21] Annika Hoyer, PhD,[22] György Jermendy, DSc,[23] Prof Alexandra Kautzky-Willer, MD,[24, 25] Prof Ilmo Keskimäki, PhD,[8, 26] Prof Dae Jung Kim, MD,[21] Zoltán Kiss, MD,[27] Prof Peter Klimek, PhD,[28, 29] Maya Leventer-Roberts, MD,[9, 30] Chun-Yi Lin, MSc,[31] Paz Lopez-Doriga Ruiz, MD,[18, 32] Andrea O Y Luk, MD,[15] Stefan Ma, PhD,[33] Manel Mata-Cases, PhD,[34, 35] Prof Dídac Mauricio, MD,[34, 35, 36] Stuart McGurnaghan, BSc,[37] Prof Tomoaki Imamura, MD,[38] Prof Sanjoy K Paul, PhD,[39] Prof Anna Peeters, PhD,[40] Santa Pildava, MD,[41] Prof Avi Porath, MD,[42, 43] Cynthia Robitaille, MSc,[17] Maria Carla Roncaglioni, MSc,[10] Takehiro Sugiyama, MD,[44, 45, 46] Kang-Ling Wang, MD,[31] Prof Sarah H Wild, PhD,[37] Naama Yekutiel, MSc,[42] Prof Jonathan E Shaw, MD,[1, 2*] Prof Dianna J Magliano, PhD,[1, 2*]

[1]Baker Heart and Diabetes Institute, Melbourne, Australia

[2]School of Public Health and Preventive Medicine, Monash University, Melbourne, Australia

[3]Centre for Medicine Use and Safety, Monash University, Melbourne, Australia

[4]Department of Mathematics and Statistics, La Trobe University, Melbourne, Australia

[5]Melbourne School of Population and Global Health, The University of Melbourne, Melbourne, Australia

[6]Department of Epidemiology and Biostatistics, School of Public Health, Imperial College London, London, United Kingdom

[7]Division of Diabetes Translation, Centers for Diseases Control and Prevention, Atlanta, GA, United States

[8]Welfare State Research and Reform, Finnish Institute for Health and Welfare, Helsinki, Finland

[9]Clalit Research Institute, Clalit Health Services, Tel Aviv, Israel

[10]Laboratory of Cardiovascular Prevention, Mario Negri Institute for Pharmacological Research IRCCS, Milan, Italy

[11]Department of General Practice, Netherlands Institute for Health Services Research, Utrecht, Netherlands

[12]Institute for Biometrics and Epidemiology, German Diabetes Center, Duesseldorf, Germany

[13]Chair of Medical Biometry and Epidemiology, Medical Faculty, University Witten/Herdecke, Germany

[14]Clinical Epidemiology, Steno Diabetes Center Copenhagen, Gentofte, Denmark

[15]Department of Medicine and Therapeutics, Li Ka Shing Institute of Health Sciences, Hong Kong Institute of Diabetes and Obesity, The Chinese University of Hong Kong, Prince of Wales Hospital, Hong Kong Special Administrative Region, China

[16]Department of Non-Communicable Diseases and Trauma, Santé Publique France, Saint-Maurice, France

[17]Centre for Surveillance and Applied Research, Public Health Agency of Canada, Ottawa, ON, Canada

[18]Department for Chronic Diseases, Norwegian Institute of Public Health, Oslo, Norway

[19]Center of Health Information, Institute of Hygiene, Vilnius, Lithuania

[20]Mykolas Romeris University (MRU) Faculty of Public Governance and Business, Vilnius, Lithuania

[21]Department of Endocrinology and Metabolism, Ajou University School of Medicine, Suwon, South Korea

[22]Biostatistics and Medical Biometry, Medical School EWL, Bielefeld University, Bielefeld, Germany

[23]3rd Medical Department, Bajcsy-Zsilinszky Hospital, Budapest, Hungary

[24]Department of Medicine III, Endocrinology and Metabolism, Medical University of Vienna, Wien, Austria

[25]Gender Institute, Gars am Kamp, Austria

[26]Faculty of Social Sciences, Tampere University, Tampere, Finland

[27]2nd Department of Medicine and Nephrological Center, Medical Faculty, University of Pécs, Pécs, Hungary

[28]Section for Science of Complex Systems, Medical University of Vienna, Vienna, Austria

[29]Complexity Science Hub Vienna, Vienna, Austria

[30]Department of Pediatrics and Department of Environmental Medicine and Public Health, Icahn School of Medicine at Mount Sinai, New York, NY, United States

[31]General Clinical Research Center, Taipei Veterans General Hospital, Taipei, Taiwan

[32]Department of Endocrinology, Morbid Obesity and Preventive Medicine, Oslo University Hospital, Oslo, Norway

[33]Epidemiology and Disease Control Division, Public Health Group, Ministry of Health, Singapore

[34]CIBER of Diabetes and Associated Metabolic Diseases, Instituto de Salud Carlos III (ISCIII), Barcelona, Spain

[35]Institut Català de la Salut, Unitat de Suport a la Recerca Barcelona Ciutat, Institut Universitari d'Investigació en Atenció Primària Jordi Gol (IDIAP Jordi Gol), Barcelona, Spain

[36]Department of Endocrinology, Hospital de la Santa Creu i Sant Pau, Autonomous University of Barcelona, Barcelona, Spain

[37]Usher Institute, University of Edinburgh, Edinburgh, Scotland

[38]Department of Public Health, Health Management and Policy, Nara Medical University, Nara, Japan

[39]Melbourne EpiCentre, University of Melbourne, Melbourne, Australia

[40]Institute for Health Transformation, Deakin University, Melbourne, Australia

[41]Research and Health Statistics Department, Centre for Disease Prevention and Control, Riga, Latvia

[42]Research Institute, Maccabi Healthcare Services, Tel Aviv, Israel

[43]Faculty of Health, Ben Gurion University, Beer-Sheva, Israel

[44]Diabetes and Metabolism Information Center, Research Institute, National Center for Global Health and Medicine, Tokyo, Japan

[45]Institute for Global Health Policy Research, Bureau of International Health Cooperation, National Center for Global Health and Medicine, Tokyo, Japan

[46]Department of Health Services Research, Faculty of Medicine, University of Tsukuba, Japan

Corresponding author:
Dunya Tomic
Level 4, 99 Commercial Road, Melbourne VIC 3004 Australia
Dee.Tomic@baker.edu.au
+61 4 131 522

*JES and DJM are joint senior authors.

Summary

*Background:* Lifetime risk, life expectancy and years of life lost are meaningful metrics for clinical decision-makers to use in diabetes care. We incorporated data from 23 high-income jurisdictions to investigate the magnitude of and trends in these measures for type 2 diabetes (T2DM).

*Methods:* T2DM incidence and mortality rates in those with and without T2DM were calculated in sex-stratified, age- and calendar year-adjusted Poisson models for each jurisdiction. Using these rates, we constructed life tables for people aged 20 to 100 years in both sexes for each jurisdiction, at two time points in the period 2005-2019. 95% confidence intervals of lifetime risk, life expectancy and years of life lost were estimated using parametric bootstrapping.

*Findings:* Lifetime risk of T2DM ranged between 16·3% (15·6 – 17·0) and 59·6% (58·5 – 60·8), with highest risks seen in Asian jurisdictions. Lifetime risk declined in 11 of 15 jurisdictions. The life expectancy gap between those with and without T2DM declined substantially in Latvia from 2010-11 to 2015-16, and in the United States from 2009-10 and 2014-15. Years of life lost to T2DM declined in some jurisdictions, most notably by 2·7 years (2·7 – 2·8) in males in the United States but increased slightly in others.

*Interpretation:* Despite declining lifetime risk and improvements in life expectancy for those with T2DM in many high-income jurisdictions, the burden of T2DM remains substantial. Public health strategies may benefit from tailored approaches to continue improving health outcomes for people with diabetes.

*Funding:* US Centers for Disease Control and Prevention, Diabetes Australia.

Research in context

*Evidence before this study:* We searched PubMed for English language articles published between 1990 and 2022 using the search terms "diabetes" AND "lifetime risk" OR "life expectancy" OR "years of life lost". We found country level studies reporting these metrics for type 2 diabetes (T2DM) in the US, Australia, Denmark, Brazil, and Germany. Few studies investigated trends over time using contemporary actual data, and none compared observations across jurisdictions.

*Added value of this study:* Using data from 23 population-based datasets from high-income jurisdictions across Europe, Asia, North America, and Oceania, we estimated lifetime risk, life expectancy and years of life lost to T2DM for two time points five years apart per jurisdiction in the period 2005-2019. We showed that the lifetime risk of T2DM is declining in most jurisdictions; however, it remains in the vicinity of 50% for several jurisdictions, especially those in Asia. Life expectancy for those with T2DM is increasing, mostly in line with the increase seen for those without T2DM, however in Latvia and the United States the increase is substantially greater for those with T2DM. There is great variation in years of life lost to the disease.

*Implications of all the available evidence:* With T2DM incidence declining, there has been a corresponding decrease in lifetime risk of the disease in many high-income jurisdictions. Although the diabetes burden, when examined at the individual level, is decreasing, it remains high. Greater emphasis on this substantial individual burden may facilitate diabetes advocacy and patient counselling.

Introduction

Diabetes is a major public health issue. In 2017, it was estimated that 451 million adults lived with diabetes, and this is estimated to increase to nearly 700 million by 2045.[1] Incidence, prevalence and mortality data have underpinned our understanding of the burden of diabetes. However, metrics such as lifetime risk, life expectancy, and years of life lost to diabetes provide an often more meaningful perspective for clinical and public health decision making. These metrics have been reported in jurisdictions including the US,[2] Australia,[3] Denmark,[4] Brazil[5] and Germany.[6] However, to date there has been no analysis incorporating data from multiple jurisdictions. Because these metrics are a consequence of both incidence and mortality rates, they need to be estimated from models that integrate the impact of these rates across the life course. In this study, we projected lifetime risk, life expectancy and years of life lost to type 2 diabetes (T2DM) using population-based datasets from 23 high-income jurisdictions over the period 2005-2019.

Methods

*Data sources and procedures*

Data sources were identified through a systematic review of diabetes incidence[7] and networks of the investigators. The search strategy of the review can be found in the appendix (p. 2). All titles and abstracts in the review were screened by at least two authors. To contribute, data sources needed to have ongoing enrolment of new members; record incident diabetes; record sex- and age-specific data; and include at least 5,000 people in the population at risk of developing diabetes in each year. For incident diabetes cases, T2DM was used where data were available on diabetes type. As ~90% of prevalent diabetes is T2DM,[8] and cases of T2DM represented an even higher proportion of all incident diabetes cases in our data sources where diabetes was split by type, all diabetes was used as a proxy for T2DM in the 11 jurisdictions in which type-specific information was unavailable. We sourced data from 23 jurisdictions, either whole countries or regions of a country. The jurisdictions included were Australia; Austria; Canada; Denmark; Finland; France; Germany; Hong Kong; Hungary; Israel; Italy; Japan; Latvia; Lithuania; Netherlands; Norway; Scotland; Singapore; South Korea; Spain; Taiwan; United Kingdom; and United States. Five data sources were not whole countries: the two Israeli data sources, which comprised two of Israel's four health services; Canada (for which the data source excluded Yukon Territory and Saskatchewan); Italy (for which the source only included the Lombardy region); and Spain (for which the source only included the Catalonia region). Summary characteristics of the jurisdictions' data, including how diabetes types were separated where possible, can be found in the appendix (p 3). Diabetes definitions varied across jurisdictions and used either clinical diagnosis, prescriptions for diabetes medications, various algorithms (e.g.,

combination of hospital discharge codes, prescriptions for diabetes medications and laboratory tests), or self-report (US only). Details on these definitions for each jurisdiction can be found in the appendix (p 4). Measurement of incidence within each dataset was consistent across time. For jurisdictions that did not split data by diabetes type, all diabetes, rather than T2DM specifically, was used in the analysis. The Alfred Health Human Research Ethics Committee approved this study. Patient consent was not required.

*Estimating incidence and mortality rates*

We modelled T2DM incidence rates ($\lambda$) and mortality rates in those with no T2DM ($\mu_{ND}$) and those with T2DM ($\mu_{DM}$) using events (incident cases, deaths) as outcome and person-years as offset in Poisson regression with a spline effect of age (coded as midpoint of the age-class) and calendar time (coded as midpoint of the year) as independent variables. Models were estimated separately for each sex and jurisdiction. For four jurisdictions (France, Germany, Netherlands, United Kingdom), mortality rates in those with and without T2DM could not be provided due to low quality of information on date of death. In these cases, we obtained mortality rates for these jurisdictions from the Human Mortality Database (HMD)[9] and age-specific relative risks of mortality in those with and without T2DM published in the relevant jurisdictions. Using these data, we derived age- and sex-specific mortality rates in those with and without T2DM through the relationships: $\mu_{HMD} = \mu_{DM}p + \mu_{ND}(1 - p)$ and $\mu_{DM} = \mu_{ND}RR$, where $\mu_{HMD}$ is the overall mortality rate from HMD, $p$ is the age-specific prevalence of T2DM provided by the data sources and $RR$ the age-specific relative risk of mortality associated with T2DM. This leads to $\mu_{DM} = \mu_{HMD} \times (1 - \delta)$ and $\mu_{ND} = \mu_{HMD} \times \delta$, where $\delta = 1/(1 + p(RR - 1))$. $RR$ and $p$ were assumed known without error.

*Transition probabilities*

We predicted T2DM incidence rates and mortality rates in those with and without T2DM for fixed dates at midpoints of one-year age intervals. These were used to compute one-year transition probabilities from state No T2DM to T2DM and Dead and from T2DM to Dead (figure 1). Transition probabilities were used in transition probability matrices for a multistate life table with three states (No T2DM, T2DM, Dead). For persons in the state No T2DM the probability of remaining in No T2DM is $\exp(-(\lambda + \mu_{ND})L)$, the probability of being in the state Dead after a period of $L$ (in this case one year) is $\mu_{ND}/(\lambda + \mu_{ND}) \times (1 - \exp(-(\lambda + \mu_{ND})L))$ and the probability of being in the state T2DM is $\lambda/(\lambda + \mu_{ND}) \times (1 - \exp(-\lambda + \mu_{ND})L)$. For persons in T2DM the probability of remaining in the state is $\exp(-\mu_{DM}L)$ and the probability of moving to Dead is $1 - \exp(-\mu_{DM}L)$.

*Life table modelling*

The model was used to compute survival of persons in No T2DM at a given age – the probability of being in No T2DM or T2DM, as well as the cumulative risk of diabetes – the probability of being in either T2DM or Dead after having had T2DM. We also used the model to compute survival of persons in T2DM at a given age. Calculations were done along the age-scale for fixed calendar time (using "cross-sectional" rates).

We used life table models[10] to simulate progression of a cohort of 20-year-olds free of T2DM at a certain time-point. The cohort was followed until death or age 100 years. Analyses were performed separately in males and females from two time-points per jurisdiction where possible. Each time-point was an aggregate of two consecutive calendar years. The later time-point combined the latest year of data available from a jurisdiction with the preceding calendar year. This combination was used instead of a single year to increase accuracy. The earlier time-point was the combination of years exactly five years prior to the later time-point. For jurisdictions with less than seven years of data, a single time-point was used, which combined the latest two years of data. For Austria, life tables started from age 50 years as accurate data were only available for individuals aged 50 and above. We ran two sets of life tables for those with and without T2DM. Stata (version 17·0) was used to construct life tables. Life expectancy from a given age was computed as the area under the survival curves, and lifetime lost as the difference between the expected lifetime of persons with and without T2DM at a given age.

*Confidence intervals*

Estimates of survival, lifetime risk, life expectancy and years of life lost were derived from estimated incidence and mortality rates from aggregate data from each jurisdiction. Confidence intervals for all quantities were estimated using parametric bootstrapping. We drew 1,000 estimates of parameters from the Poisson rate models from the normal distribution with mean equal to the maximum likelihood estimates (MLE) and variance-covariance equal to the inverse of the observed Fisher Information matrix. For each set of parameter estimates we computed the predicted rates and corresponding survival, lifetime risk, life expectancy, and years of life lost. This yielded 1,000 estimates of all metrics (lifetime risk, life expectancy, years of life lost), from which we used the median as the point estimate and the 2·5th and 97·5th percentiles as confidence intervals.

*Role of the funding source*

Results

In total, across all study cohorts from the 23 jurisdictions (total person-years = 1,577,234,194), there were 5,119,585 incident cases of T2DM, 4,007,064 deaths in those with T2DM, and 11,854,043 deaths in those without T2DM (appendix p 5). The peak prevalence of diabetes of 45·8% occurred in Singaporean males aged 85 and above in 2015-16.

Lifetime risk of T2DM was calculated to determine the percentage of each cohort that develops T2DM by age 100 from age 20. There was great variation between jurisdictions, with estimated lifetime risk as high as 59·6% (58·5 – 60·8) for Singaporean males in 2015-16, and as low as 16·3% (15·6 – 17·0) for Scottish females in 2018-19 (Table 1). Lifetime risk

decreased for both sexes in most jurisdictions. The decrease was most substantial in US males, where lifetime risk decreased from 54·0% (53·8 – 54·2) in 2009-10 to 33·1% (33·0 – 33·2) in 2014-15. Lifetime risk was generally higher for males compared to females in the same jurisdiction. When life tables were run to age 80 instead of age 100, risk of diabetes before age 80 ranged from 14·4% (14·0 – 14·7) to 53·8% (52·8 – 54·7) (appendix p 8).

Amongst people with T2DM, the highest life expectancies were seen for both sexes in Japan in 2017-18 (Table 2), where the average life expectancy at age 20 years was 59·2 (59·2 – 59·3) for a man with T2DM, and 64·1 (64·0 – 64·2) for a woman with T2DM. The lowest life expectancy for males with T2DM at age 20 years of 43·7 (42·7 – 44·6) was observed in 2013-14 in Lithuania. In females with T2DM, the lowest life expectancy at age 20 years of 54·2 (53·4 – 54·9) occurred in Latvia in 2010-11. Life expectancy in people with T2DM increased over time for both sexes in all jurisdictions except Spain and Scotland (appendix p 11). This change was generally commensurate with the increase observed for people without T2DM. However, in Latvia, substantially greater increases were observed for those with T2DM. Also, in US males, life expectancy increased by 2·3 years for males with T2DM between 2009-10 and 2014-15 whilst falling by 0·4 years in males without T2DM. With increasing age at incident T2DM, the effect of T2DM in reducing life expectancy was reduced. Tables for life expectancy in those with and without T2DM at ages 40 and 60 can be found in the appendix (pp 6–7).

The highest values for years of life lost for those with T2DM at age 20 were observed in Israel (Clalit) for both sexes (Figures 2 and 3). In males, this occurred in 2015-16, where an average 20-year-old male with T2DM was expected to lose 12·9 years over the course of his lifetime compared to a male without T2DM at the same age. The average 20-year-old female with T2DM in Israel (Clalit) was expected to lose 11·2 years compared to her counterpart without T2DM in both 2010-11 and 2015-16. The lowest value for males occurred in Latvia in 2015-16, where expected years lost at age 20 was 2·5, whereas the lowest value in females occurred in Finland in 2016-17, where expected years lost at age 20 was 3·1. Over time, expected years lost to T2DM decreased in some jurisdictions while increasing in others. In males, the greatest decrease in years of life lost to T2DM at age 20 of 2·7 years occurred in the US between 2009-10 and 2014-15, while in females the greatest decrease of 1·5 years was seen in Latvia between 2010-11 and 2015-16. The greatest increases of 0.7 and 0.6 years for males and females respectively occurred in Hong Kong between 2013-14 and 2018-19. Fewer years of life were lost to T2DM among those with T2DM at age 40 and 60 than among those with T2DM at age 20 (appendix p 11). In Austria, expected years of life lost from age 50 were 4·0 in males and 3·6 in females.

In a sensitivity analysis that tested the effect of varying inputs into the life table models, we found that incidence had the most substantial effect on lifetime risk, while changes to mortality rates and relative risks of mortality altered results for years of life lost (appendix pp 9–10).

Discussion

Using life table modelling, we have estimated the lifetime risk of T2DM, life expectancy in people with and without T2DM, and years of life lost to T2DM in 23 high-income settings.

We found that lifetime risk of T2DM varied from 16·3% – 59·6%; life expectancy for those with T2DM at age 20 years varied from 43·7 – 59·3 years in males and 54·2 – 64·3 years in females; and years of life lost to T2DM ranged from 2·5 – 12·9 years. Our findings demonstrate the substantial burden of diabetes across many jurisdictions using metrics that can be easily interpreted by individuals in these jurisdictions and are valuable for use in prevention and counselling.

One of the most pertinent findings is the decrease in lifetime risk of T2DM in most jurisdictions, which is driven by declining diabetes incidence in many high-income settings. In a systematic review of 23 population-based studies published between 1995 and 2018 reporting trends in diabetes incidence, 19 data sources showed a downward or stable trend in diabetes incidence, with which our results are closely aligned.[11] Another important finding is the substantial magnitude of the lifetime risk observed in many jurisdictions. Despite declining lifetime risk in 11 of the 15 jurisdictions where two time-points were studied, lifetime risk remained greater than 30% in most jurisdictions and over 50% in Israel and Hong Kong. However, using methods like ours, even higher figures for lifetime risk have been reported in other studies. An Indian study reported lifetime risk of diabetes as 55·5% in males and 64·6% in females.[12] Our findings are also understandable in the context of studies reporting lifetime risks of other conditions. The cumulative risk of developing cancer by age 85 amongst the British population born in 1960 was found to be 49·8% for males and 39·9% for females.[13] A US analysis found lifetime risks of 90% for hypertension amongst 55- and 65-year-olds.[14]

We also reinforce the great differences in life expectancy for people with diabetes between jurisdictions, which were generally commensurate to World Bank data[15] on government health expenditure as a proportion of gross domestic product. The observation of decreased life expectancies in those with and without T2DM in Spain between 2010-11 and 2015-16 aligns with the decrease in Spanish public healthcare expenditure from 2009 following the global financial crisis.[16] The lowest life expectancies observed in Latvian and Lithuanian males are consistent with evidence showing a high prevalence of smoking and other high-risk behaviours among males of young and middle age in these countries, increasing the risk of fatal accidents and injuries.[17] Regarding years of life lost due to diabetes, the greatest values were observed in Israel's Clalit Health Services population, which may be in part explained by the fact that the Clalit health insurance database includes a high proportion of individuals of lower socioeconomic status (SES).[18] Individuals of lower SES with diabetes may experience barriers in accessing the healthcare required to bring their life expectancies closer to those of the general population. Compared to higher SES, lower SES is also associated with decreased health literacy, poorer diet, and more sedentary lifestyle, which can lead to lower life expectancy.[19] The other outlier regarding years of life lost was Taiwan. However, a previous population-based Taiwanese study reported that life expectancy at age 30 was 10·2 and 11·7 years less for males and females respectively with diabetes and no chronic kidney disease (CKD) compared to those with no diabetes and no CKD.[20] Population median age and health system factors may also contribute to the wide range of observations for years of life lost across jurisdictions.

Our findings are consistent with observations from previous studies and subsequent trends in diabetes incidence and mortality rates. Compared to a 2008 Australian study,[3] we

reported lower lifetime risk and years of life lost to T2DM, whilst observing higher life expectancies amongst those with T2DM, which is expected given improvements in diabetes care. Similarly, our findings for life expectancy were higher and years of life lost were lower than in a Canadian study from 2004-06.[21] Compared to the most recent US study using 2000-11 data,[2] we found higher lifetime risk in our first time point (2009-10), but lower risk at our second time point (2014-15). This is in keeping with the finding that, after diabetes incidence increased in the US from 1990 to 2007, it decreased significantly from 2007 to 2017.[22] Concurrently, excess mortality in those with diabetes almost halved in the US between 1994 and 2015.[23] Compared to a Danish study incorporating data from 1996-2016, we obtained similar results for lifetime risk.[4] Our lifetime risk results for the Netherlands are almost identical to an earlier analysis using data from 1997-2012.[24] Since that study used ages 45 and above in their life tables, it can be deduced that lifetime risk reduced in the Netherlands in the time between the previous research and our analysis which simulated life tables from age 20 in 2015-16. In Germany, a study using 2015 data to run life tables from ages 40 to 100 reported years of life lost of 5·8 in males and 4·2 in females in a scenario where incidence and mortality rate ratio (MRR) were constant.[6] Our figures from age 40 of 6·3 in males and 6·4 in females are higher, which could be explained by the fact we used earlier data from 2013-14 and a different equation to estimate MRR.

The major strength of our study is the use of multiple, population-based datasets. Unlike previous estimates that use modelled incidence and mortality data, our analysis used real world populations. All data sources were assessed for quality in a previous analysis[11] using a modified Newcastle-Ottawa scale. The domains assessed were representativeness of the population; sample size; assessment of diabetes; exclusion of gestational diabetes; and completeness (duration of data provided). Out of a maximum score of eight, all data sources received scores of between three and eight. The minimum score was received by the Netherlands due to issues in population representativeness, diabetes assessment, and short duration of data provided. Most data sources incorporated all people with known diabetes in a country. One limitation is that our study only measures diagnosed diabetes. The 2021 International Diabetes Federation (IDF) Atlas showed that 29% of diabetes cases across 81 data sources from high-income countries were undiagnosed.[25] As our life tables applied incidence and mortality rates from a single time point to a cohort, changes to these rates that would have occurred over the lifetime of the cohort could not be applied. For sources that did not provide mortality data, mortality rates had to be estimated using relative risks. However, the rates used in our estimations were obtained from recent publications from the relevant jurisdictions and show comparable results to those from studies conducted in those jurisdictions. Our life expectancy figures also align closely with Global Burden of Disease (GBD) data[26] for life expectancy at age 20 in the years and specific jurisdictions we analysed. Methods used to diagnose T2DM varied across jurisdictions and in some cases within jurisdictions over time. In those jurisdictions, where the data included total diabetes rather than only T2DM, our estimates of lifetime risk of T2DM and number of years lost to T2DM will be slightly overestimated. Further, in such jurisdictions, our estimates of life expectancy of those with T2DM would be slightly underestimated as those with type 1 diabetes typically have shorter life expectancies compared to those with T2DM.[27] Our findings are limited in their generalisability as no data from low- and middle-income countries (LMICs) were included.

As the cohorts in the life table analyses represent a group of homogenous individuals, the findings represent an average member of the population. Each person will carry a unique combination of risk factors that will affect their risk of mortality and developing T2DM. However, our findings can be used to encourage individuals to take preventive action by presenting findings specific to their jurisdiction. Caution should be exercised in interpreting life expectancy estimates, since they are based on cross-sectional rates (from the study period). In this respect our measures do not differ from other standard demographic measures published. In conclusion, we have shown that, although the burden of T2DM at the individual level is declining, it remains substantial. Lifetime risk, life expectancy, and years of life lost are unique metrics that, in tandem with population-oriented metrics such as prevalence and mortality, provide a more rounded picture of the disease burden of diabetes. These metrics are useful for counselling in the clinical setting and may encourage individuals with diabetes to take preventive action to optimise their future health outcomes.

References

1.      Cho NH, Shaw JE, Karuranga S, et al. IDF Diabetes Atlas: Global estimates of diabetes prevalence for 2017 and projections for 2045. *Diabetes Res Clin Pract* 2018; **138**: 271-81.
2.      Gregg EW, Zhuo X, Cheng YJ, Albright AL, Narayan KMV, Thompson TJ. Trends in lifetime risk and years of life lost due to diabetes in the USA, 1985-2011: A modelling study. *Lancet Diabetes Endocrinol* 2014; **2**(11): 867-74.
3.      Magliano DJ, Shaw JE, Shortreed SM, et al. Lifetime risk and projected population prevalence of diabetes. *Diabetologia* 2008; **51**(12): 2179-86.
4.      Carstensen B, Rønn PF, Jørgensen ME. Lifetime risk and years lost to type 1 and type 2 diabetes in Denmark, 1996-2016. *BMJ Open Diabetes Res Care* 2021; **9**(1).
5.      Bracco PA, Gregg EW, Rolka DB, et al. Lifetime risk of developing diabetes and years of life lost among those with diabetes in Brazil. *J Glob Health* 2021; **11**: 04041.
6.      Tönnies T, Baumert J, Heidemann C, von der Lippe E, Brinks R, Hoyer A. Diabetes free life expectancy and years of life lost associated with type 2 diabetes: projected trends in Germany between 2015 and 2040. *Popul Health Metr* 2021; **19**(1).
7.      Magliano DJ, Islam RM, Barr ELM, et al. Trends in incidence of total or type 2 diabetes: Systematic review. *BMJ* 2019; **366**.
8.      Gershell L. Type 2 diabetes market. *Nature Reviews Drug Discovery* 2005; **4**(5): 367-8.
9.      University of California BU, and Max Planck Institute for Demographic Research (Germany). Human Mortality Database. University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany): University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany); 2021.
10.     Preston S, Heuveline, P., Guillot, M. Demography: Measuring and Modeling Population Processes: Wiley-Blackwell; 2000.
11.     Magliano DJ, Chen L, Islam RM, et al. Trends in the incidence of diagnosed diabetes: a multicountry analysis of aggregate data from 22 million diagnoses in high-income and middle-income settings. *Lancet Diabetes Endocrinol* 2021; **9**(4): 203-11.
12.     Luhar S, Kondal D, Jones R, et al. Lifetime risk of diabetes in metropolitan cities in India. *Diabetologia* 2021; **64**(3): 521-9.
13.     Ahmad AS, Ormiston-Smith N, Sasieni PD. Trends in the lifetime risk of developing cancer in Great Britain: Comparison of risk for those born from 1930 to 1960. *Br J Cancer* 2015; **112**(5): 943-7.
14.     Vasan RS, Beiser A, Seshadri S, et al. Residual lifetime risk for developing hypertension in middle-aged women and men: The Framingham Heart Study. *J Am Med Assoc* 2002; **287**(8): 1003-10.
15.     The World Bank. Health Nutrition and Population Statistics. Washington, DC: The World Bank, 2022. Available from https://databank.worldbank.org/source/health-nutrition-and-population-statistics. (Accessed 23 April 2022).
16.     Ridao-López M, Comendeiro-Maaløe M, Martínez-Lizaga N, Bernal-Delgado E. Evolution of public hospitals expenditure by healthcare area in the Spanish National Health System: the determinants to pay attention to. *BMC Health Services Research* 2018; **18**(1): 696.
17.     Kasmel A, Helasoja V, Lipand A, Prättälä R, Klumbiene J, Pudule I. Association between health behaviour and self-reported health in Estonia, Finland, Latvia and Lithuania. *European Journal of Public Health* 2004; **14**(1): 32-6.

18.	Karpati T, Cohen-Stavi CJ, Leibowitz M, Hoshen M, Feldman BS, Balicer RD. Towards a subsiding diabetes epidemic: trends from a large population-based study in Israel. *Popul Health Metr* 2014; **12**(1): 32.

19.	Svendsen MT, Bak CK, Sørensen K, et al. Associations of health literacy with socioeconomic position, health risk behavior, and health status: a large national population-based survey among Danish adults. *BMC Public Health* 2020; **20**(1): 565.

20.	Wen CP, Chang CH, Tsai MK, et al. Diabetes with early kidney involvement may shorten life expectancy by 16 years. *Kidney Int* 2017; **92**(2): 388-96.

21.	Loukine L, Waters C, Choi BCK, Ellison J. Impact of diabetes mellitus on life expectancy and health-adjusted life expectancy in Canada. *Popul Health Metr* 2012; **10**.

22.	Benoit SR, Hora I, Albright AL, Gregg EW. New directions in incidence and prevalence of diagnosed diabetes in the USA. *BMJ Open Diabetes Res Care* 2019; **7**(1).

23.	Pearson-Stuttard J, Buckley J, Cicek M, Gregg EW. The Changing Nature of Mortality and Morbidity in Patients with Diabetes. *Endocrinol Metab Clin North Am* 2021; **50**(3): 357-68.

24.	Ligthart S, van Herpt TTW, Leening MJG, et al. Lifetime risk of developing impaired glucose metabolism and eventual progression from prediabetes to type 2 diabetes: A prospective cohort study. *Lancet Diabetes Endocrinol* 2016; **4**(1): 44-51.

25.	Ogurtsova K, Guariguata L, Barengo NC, et al. IDF diabetes Atlas: Global estimates of undiagnosed diabetes in adults for 2021. *Diabetes Res Clin Pract* 2022; **183**: 109118.

26.	Institute for Health Metrics and Evaluation (IHME). GBD Compare Data Visualization. Seattle, WA: IHME, University of Washington, 2020. Available from http://vizhub.healthdata.org/gbd-compare. (Accessed 01 February 2022).

27.	Heald AH, Stedman M, Davies M, et al. Estimating life years lost to diabetes: outcomes from analysis of National Diabetes Audit and Office of National Statistics data. *Cardiovascular Endocrinology & Metabolism* 2020; **9**(4).

28.	Centers for Disease Control and Prevention. NHIS Data, Questionnaires and Related Information. 2022. https://www.cdc.gov/nchs/nhis/data-questionnaires-documentation.htm (accessed 27 June 2022).

Figures

Figure 1: Visual representation of the life table states and associated transition probabilities.

*The multi-state life table included the three states of No T2DM, T2DM, and Dead. For those in the state No T2DM, the probability of remaining in No T2DM is* exp(-($\lambda$ + $\mu_{ND}$)L))*, and the probabilities of transitioning to T2DM or Dead are given above. For those in T2DM, the probability of remaining in T2DM is* exp(-$\mu_{DM}$L) *and the probability of transitioning to Dead is given above.* $\lambda$ = T2DM incidence rate; $\mu_{ND}$ = mortality rate in those without T2DM; $\mu_{DM}$ = mortality rate in those with T2DM; L = probability of being in the state Dead after period of one year.

Figure 2: Years of life lost to type 2 diabetes at age 20 by jurisdiction, males

*Clalit = Clalit Health Services; Maccabi = Maccabi Health Services. Dashed line represents line of unity, with points to the right of the line representing greater years lost at first time-point.*

Figure 3: Years of life lost to type 2 diabetes at age 20 by jurisdiction, females

*Clalit = Clalit Health Services; Maccabi = Maccabi Health Services. Dashed line represents line of unity, with points to the right of the line representing greater years lost at first time-point.*

Legend for Figures 2 and 3:

*Au =* Australia
*Ca =* Canada
*De =* Denmark
*Fi =* Finland
*HK =* Hong Kong
*IC =* Israel (Clalit)
*IM =* Israel (Maccabi)
*It =* Italy
*La =* Latvia
*Li =* Lithuania
*Sc =* Scotland
*SK =* South Korea
*Sp =* Spain
*Ta =* Taiwan
*UK =* United Kingdom
*US =* United States