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Body-mass index and diabetes risk in 57 low-income and middle-income countries: a cross-sectional study of nationally representative, individual-level data in 685 616 adults

Felix Teufel, Jacqueline A Seiglie*, Pascal Geldsetzer, Michaela Theilmann, Maja E Marcus, Cara Ebert, William Andres Lopez Arboleda, Kokou Agoudavi, Glennis Andall-Brereton, Krishna K Aryal, Brice Wilfried Bicaba, Garry Brian, Pascal Bovet, Maria Dorobantu, Mongal Singh Gurung, David Guwatudde, Corine Houehanou, Dismand Houinato, Jutta M Adelin Jorgensen, Gibson B Kagaruki, Khem B Karki, Demetre Labadarios, Joao S Martins, Mary T Mayige, Roy Wong McClure, Joseph Kibachio Mwangi, Omar Mwalim, Bolormaa Norov, Sarah Crooks, Farshad Farzadfar, Sahar Saeedi Moghaddam, Bahendeka K Silver, Lela Sturua, Chea Stanford Wesseh, Andrew C Stokes, Utibe R Essien, Jan-Walter De Neve, Rifat Atun, Justine I Davies, Sebastian Vollmer, Till W Bärnighausen, Mohammed K Ali, James B Meigs, Deborah J Wexler, Jennifer Manne-Goehler*

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*Contributed equally

Heidelberg Institute of Global Health, Faculty of Medicine and University Hospital, Heidelberg University, Heidelberg, Germany (F Teufel BM, P Geldsetzer ScD, M Theilmann MA, W A L Arboleda MSc, J-W De Neve MD, Prof T W Bärnighausen MD); **Diabetes Unit** (J A Seiglie MD, D J Wexler MD), **Department of General Internal Medicine** (Prof J B Meigs MD), **and Medical Practice Evaluation Center** (J Manne-Goehler MD), **Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA; Department of Medicine** (J A Seiglie, J B Meigs, D J Wexler, J Manne-Goehler), **and Division of Infectious Diseases, Brigham and Women's Hospital** (J Manne-Goehler) **Harvard Medical School, Boston, MA, USA; Department of Medicine, Division of Primary Care and Population Health, Stanford University, Stanford, CA, USA** (P Geldsetzer); **Department of Economics and Centre for Modern Indian Studies, University of Goettingen, Göttingen, Germany** (M E Marcus MA, Prof S Vollmer PhD); **RWI—Leibniz Institute for Economic Research, Essen (Berlin Office), Germany** (C Ebert PhD); **Togo Ministry of Health, Lome, Togo** (K Agoudavi MD); **Caribbean Public Health Agency, Port of Spain, Trinidad and Tobago** (G Andall-Brereton PhD, S Crooks MSc); **Nepal Health Sector Programme 3, Monitoring Evaluation and**

Summary

Background The prevalence of overweight, obesity, and diabetes is rising rapidly in low-income and middle-income countries (LMICs), but there are scant empirical data on the association between body-mass index (BMI) and diabetes in these settings.

Methods In this cross-sectional study, we pooled individual-level data from nationally representative surveys across 57 LMICs. We identified all countries in which a WHO Stepwise Approach to Surveillance (STEPS) survey had been done during a year in which the country fell into an eligible World Bank income group category. For LMICs that did not have a STEPS survey, did not have valid contact information, or declined our request for data, we did a systematic search for survey datasets. Eligible surveys were done during or after 2008; had individual-level data; were done in a low-income, lower-middle-income, or upper-middle-income country; were nationally representative; had a response rate of 50% or higher; contained a diabetes biomarker (either a blood glucose measurement or glycated haemoglobin [HbA_{1c}]); and contained data on height and weight. Diabetes was defined biologically as a fasting plasma glucose concentration of 7·0 mmol/L (126·0 mg/dL) or higher; a random plasma glucose concentration of 11·1 mmol/L (200·0 mg/dL) or higher; or a HbA_{1c} of 6·5% (48·0 mmol/mol) or higher, or by self-reported use of diabetes medication. We included individuals aged 25 years or older with complete data on diabetes status, BMI (defined as normal [18·5–22·9 kg/m²], upper-normal [23·0–24·9 kg/m²], overweight [25·0–29·9 kg/m²], or obese [≥30·0 kg/m²]), sex, and age. Countries were categorised into six geographical regions: Latin America and the Caribbean, Europe and central Asia, east, south, and southeast Asia, sub-Saharan Africa, Middle East and north Africa, and Oceania. We estimated the association between BMI and diabetes risk by multivariable Poisson regression and receiver operating curve analyses, stratified by sex and geographical region.

Findings Our pooled dataset from 58 nationally representative surveys in 57 LMICs included 685 616 individuals. The overall prevalence of overweight was 27·2% (95% CI 26·6–27·8), of obesity was 21·0% (19·6–22·5), and of diabetes was 9·3% (8·4–10·2). In the pooled analysis, a higher risk of diabetes was observed at a BMI of 23 kg/m² or higher, with a 43% greater risk of diabetes for men and a 41% greater risk for women compared with a BMI of 18·5–22·9 kg/m². Diabetes risk also increased steeply in individuals aged 35–44 years and in men aged 25–34 years in sub-Saharan Africa. In the stratified analyses, there was considerable regional variability in this association. Optimal BMI thresholds for diabetes screening ranged from 23·8 kg/m² among men in east, south, and southeast Asia to 28·3 kg/m² among women in the Middle East and north Africa and in Latin America and the Caribbean.

Interpretation The association between BMI and diabetes risk in LMICs is subject to substantial regional variability. Diabetes risk is greater at lower BMI thresholds and at younger ages than reflected in currently used BMI cutoffs for assessing diabetes risk. These findings offer an important insight to inform context-specific diabetes screening guidelines.

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Introduction

The global prevalence of overweight and obesity has doubled over the past four decades, with 1·9 billion (39%) adults living with overweight, and an additional 650 million (13%) adults living with obesity in 2016.[1,2] Although studies published in the past 5 years suggest that the rate of increase in overweight and obesity in high-income countries might be slowing,[2,3] there is

Research in context

Evidence before this study

We searched PubMed (with the medical subject heading search tool) on April 15, 2020, using the terms "body mass index" OR "anthropometry" AND "diabetes mellitus" AND "low- and middle-income countries" NOT "comment" NOT "case reports". We searched for manuscripts published in any language from database inception to April 15, 2020. We found two pooled studies on the association between body-mass index (BMI) and diabetes. One study pooled nationally representative surveys from six low-income and middle-income countries (LMICs) and evaluated the association between BMI categories and non-communicable disease multimorbidity (including nine chronic conditions, one of which was diabetes). The second study pooled data on 900 000 individuals recruited from 18 cohorts across seven Asian countries and did not include nationally representative data. Several large studies on the prevalence and projected trends of overweight, obesity, and diabetes across LMICs have been published, but none of these studies have evaluated the association between BMI and diabetes risk in these settings and how this association varies by geographical region and sex.

Added value of this study

To our knowledge, this study uses the largest harmonised dataset collected to date of nationally representative, individual-level data on BMI and a biological measure of diabetes in 685 616 adults across 57 LMICs spanning six world regions. We did robust analyses, stratified by sex and geographical region, to assess the association between BMI (as a continuous and categorical exposure) and diabetes, defined biologically as a fasting plasma glucose concentration of 7·0 mmol/L (126·0 mg/dL) or higher; a random plasma glucose concentration of 11·1 mmol/L (200·0 mg/dL) or higher; or a glycated haemoglobin of 6·5% (48·0 mmol/mol) or higher, or by self-reported use of diabetes medication. We also present receiver operating curve analyses of optimal BMI cutoffs when assessing diabetes risk. The results show substantial variability in the association between BMI and diabetes risk by region and sex, and they add to our current understanding of the association between BMI and diabetes risk in countries poorly represented in previous literature.

Implications of all the available evidence

Given the rapidly growing burden of overweight, obesity, and diabetes in LMICs, urgent population-level strategies are needed to reverse current and projected trends. Additionally, our findings highlight that interventions and the BMI thresholds at which clinicians and policy makers consider metabolic risk to be increased vary across LMICs. Finally, in specific regions, screening might also need to include younger adults than is currently recommended by most guidelines.

growing evidence that this epidemic has accelerated in low-income and middle-income countries (LMICs), where approximately 67% of people with obesity now reside.[4–6] The unprecedented increase in overweight and obesity in LMICs has paralleled the alarming rise in the prevalence of diabetes and other cardiovascular risk factors in these countries, such that 79% of the estimated 463 million people with diabetes reside in LMICs.[7] However, data on how overweight and obesity, measured with standard metrics such as body-mass index (BMI), relate to diabetes risk across LMICs, and whether the variation observed in country-level studies is also observed at larger geographical scales are scarce.

Although the association between high BMI and metabolic risk is well established,[8,9] the current understanding of BMI and its association with key clinical outcomes has been shaped by a vast number of studies that have, to date, almost exclusively been done in high-income countries.[8,10,11] The exception has been the increasing number of studies done in Asian and south Asian countries,[12–14] which have directly informed clinical guidelines recommending the lowering of BMI thresholds that define overweight to better characterise metabolic risk in these populations.[14] Importantly, single-country studies in LMICs have also indicated variability in the association between BMI and diabetes risk when standard BMI thresholds are used,[15,16] but differences in this association across LMICs, which are highly heterogeneous, remain largely unexplored.

In this study, we aimed to characterise the association between BMI and diabetes risk in LMICs at the country level, and stratified by geographical region and sex. To achieve this aim, we used the largest harmonised dataset of individual-level survey data compiled to date, including biologically measured diabetes status, to characterise the risk of diabetes across the full range of BMIs in LMICs.

Methods

Data sources and study population

In this cross-sectional study, we did a pooled analysis of individual-level data from 58 nationally representative population-based surveys across 57 LMICs. The requirements for inclusion of a national survey and the search methods used have been described previously.[17,18] Further details specific to this analysis are provided in the appendix (pp 3–4). Briefly, eligible surveys were done during or after 2008; had individual-level data; were done in a low-income, lower-middle-income, or upper-middle-income country (according to the World Bank income group in the year the survey was done);[19] were nationally representative; had a response rate of 50% or higher; contained a diabetes biomarker (either a blood glucose measurement or glycated haemoglobin [HbA_{1c}]); and contained data on height and weight.

Operational Research Project, Abt Associates, Kathmandu, Nepal (K K Aryal PhD); **Institut National de Santé Publique, Ministère de la santé, Ouagadougou, Burkina Faso** (B W Bicaba MD); **The Fred Hollows Foundation New Zealand, Auckland, New Zealand** (G Brian MBChB); **Ministry of Health, Victoria, Seychelles** (P Bovet MD); **University Center for Primary Care and Public Health, Lausanne, Switzerland** (P Bovet); **University of Medicine and Pharmacy Carol Davila, Bucharest, Romania** (Prof M Dorobantu MD); **Health Research and Epidemiology Unit, Ministry of Health, Thimphu, Bhutan** (M S Gurung PhD); **Department of Epidemiology and Biostatistics, School of Public Health, Makerere University, Kampala, Uganda** (Prof D Guwatudde PhD); **Laboratory of Epidemiology of Chronic and Neurological Diseases, Faculty of Health Sciences, University of Abomey-Calavi, Cotonou, Benin** (C Houehanou MD, Prof D Houinato MD); **Department of Public Health, University of Copenhagen, Copenhagen, Denmark** (J M A Jorgensen MD); **National Institute for Medical Research, Dar es Salaam, Tanzania** (G B Kagaruki MSc, M T Mayige PhD); **Department of Community Medicine and Public Health, Institute of Medicine, Tribhuvan University, Kathmandu, Nepal** (K B Karki MD); **Faculty of Medicine and Health Sciences** (Prof D Labadarios PhD) **and Department of Global Health, Centre for Global Surgery** (Prof J I Davies MD), **Stellenbosch University, Stellenbosch, South Africa; Faculty of Medicine and Health Sciences, Universidade Nacional Timor Lorosae, Rua Jacinto Candido, Dili, Timor-Leste** (J S Martins PhD); **Epidemiology Office and Surveillance, Caja Costarricense de Seguro Social, San Jose, Costa Rica** (R W McClure MSc); **Division of Non-Communicable Diseases, Ministry of Health, Nairobi, Kenya** (J K Mwangi MD); **Faculté de Médecine, Université de Genève, Geneva, Switzerland**

(J K Mwangi); **Zanzibar Ministry of Health, Mnazi Mmoja, Zanzibar, Tanzania** (O Mwalim MPH); **National Center for Public Health, Ulaanbaatar, Mongolia** (B Norov MSc); **Non-Communicable Diseases Research Center, Endocrinology and Metabolism Population Sciences Institute** (Prof F Farzadfar MD) **and Endocrinology and Metabolism Research Center, Endocrinology and Metabolism Population Sciences Institute** (S S Moghaddam MSc), **Tehran University of Medical Sciences, Tehran, Iran; St Francis Hospital, Nsambya, Kampala, Uganda** (B K Silver MBChB); **Non-Communicable Diseases Department, National Center for Disease Control and Public Health, Tbilisi, Georgia** (Prof L Sturua MD); **Petre Shotadze Tbilisi Medical Academy, Tbilisi, Georgia** (Prof L Sturua); **Liberia Ministry of Health, Monrovia, Liberia** (C S Wesseh MA); **Department of Global Health, Boston University School of Public Health, Boston, MA, USA** (A C Stokes PhD); **Division of General Internal Medicine, University of Pittsburgh, Pittsburgh, PA, USA** (U R Essien MD); **Center for Health Equity Research and Promotion, Veterans Affairs Pittsburgh Healthcare System, Pittsburgh, PA, USA** (U R Essien); **Department of Global Health and Population, Harvard T H Chan School of Public Health** (Prof R Atun FRCP, Prof T W Bärnighausen) **and Department of Global Health and Social Medicine** (Prof R Atun), **Harvard University, Boston, MA, USA; MRC/Wits Rural Public Health and Health Transitions Research Unit, School of Public Health, University of Witwatersrand, Johannesburg, South Africa** (Prof J I Davies); **Institute of Applied Health Research, University of Birmingham, Birmingham, UK** (Prof J I Davies); **Africa Health Research Institute, Somkhele, South Africa** (Prof T W Bärnighausen); **Hubert Department of Global Health, Rollins School of Public Health** (Prof M K Ali MD),

We first identified all countries in which a WHO Stepwise Approach to Surveillance (STEPS) survey had been done during a year in which the country fell into an eligible World Bank income group category. The STEPS survey is a standardised instrument for collecting and disseminating data about non-communicable disease risk factors in adults living in WHO member countries.[20] Before the STEPS surveys were made available in the WHO Central Data Catalog in 2019, we systematically requested each eligible STEPS dataset from a list of these surveys that the WHO maintains in the NCD Microdata Repository. On Feb 26, 2021, additional eligible surveys were downloaded from the Central Data Catalog (final screening date Feb 26, 2021). Ultimately, we included 49 eligible STEPS surveys. The details of the STEPS survey search are provided in the appendix (p 3). For LMICs that did not have a STEPS survey that met our inclusion criteria, did not have valid contact information, or that declined our request for data (86 LMICs in total), we did a systematic search using Google and an additional search of the Demographic and Health Survey (DHS) website. We ultimately identified 19 eligible non-STEPS surveys, and included data from nine non-STEPS surveys that met the aforementioned inclusion criteria (appendix p 4). Of note, surveys were done separately for Zanzibar and Tanzania but were considered to be from one country (Tanzania). Countries were categorised into the following six geographical regions, according to the non-communicable disease Risk Factor Collaboration geographical classification:[21] east, south, and southeast Asia, Europe and central Asia, Latin America and the Caribbean, Middle East and north Africa, Oceania, and sub-Saharan Africa (full definitions are provided in the appendix [p 6]). Country-specific sampling methods for these surveys are provided in the appendix (pp 6–32).

The study adheres to the STROBE guidelines (appendix pp 71–73). This study was designated "not human subjects research" by the institutional review board of the Harvard T H Chan School of Public Health on May 9, 2018, and was thus deemed not to require additional ethical approval.

Sample and definitions

Our study population included participants aged 25 years and older. We chose this age threshold because 25 years was the minimum age for inclusion in many of the surveys used in this analysis.

Diabetes biomarkers used for diagnosis included point-of-care fasting capillary glucose, plasma equivalents, a laboratory-based measurement of fasting plasma glucose, and HbA_{1c}. Plasma equivalents were calculated for all surveys without these data by multiplying capillary glucose measurements by a factor of 1·11. This adjustment was based on published guidelines and evidence showing that capillary glucose often underestimates plasma glucose levels.[22] For surveys that did not provide details of which glucose measuring devise was used, we assumed that point-of-care fasting capillary glucose had been done because this was the most frequently used measurement across surveys (no plasma equivalent was computed given the absence of information). When the fasting status of participants was not reported, fasting was assumed because all but one survey protocol (the India National Family and Health Survey) requested fasting status. All surveys, except for the India National Family and Health Survey, required a minimum of 8 h of fasting before the plasma glucose test, which was defined as no food or drink (other than water). Details of the fasting instructions for each survey are provided in the appendix (p 34).

The presence of diabetes was defined on the basis of current WHO diagnostic thresholds as any of the following: a fasting plasma glucose of 7·0 mmol/L (126·0 mg/dL) or higher; a random plasma glucose of 11·1 mmol/L (200·0 mg/dL) or higher; or a HbA_{1c} of 6·5% (48·0 mmol/mol or higher).[23] For individuals in surveys that had both fasting plasma glucose and HbA_{1c} measurements available (China, Guyana, Iran, Romania, and Seychelles), the presence of diabetes was determined by HbA_{1c}. No differences were observed in a sensitivity analysis that defined diabetes as a fasting blood glucose of 7·0 mmol/L or higher in the presence of a HbA_{1c} of less than 6·5% (<48·0 mmol/mol; appendix pp 58, 68). Respondents who self-reported use of diabetes medication were classified as having diabetes irrespective of biomarker values. Individuals who self-reported a diagnosis of diabetes but were not on diabetes medication and did not meet the biomarker diagnostic criteria were not classified as having diabetes. No differences in the association between BMI and diabetes risk were observed when the study sample was restricted to individuals with diabetes who were not on pharmacological treatment (appendix pp 57, 67). For the STEPS and DHS, height was measured once in a standing position with a portable height measuring board, such as those from Seca (Hamburg, Germany) or Shorr Productions (Olney, MD, USA).[24,25] Weight was measured with a portable weighing scale, such as a Seca scale or the Tanita HS301 Solar Scale (Tanita, Tokyo, Japan).[24,25] BMI was calculated as weight in kg divided by the square of height in meters, and we classified BMI into the following clinical categories recommended by WHO: underweight (<18·5 kg/m²), normal (18·5–22·9 kg/m²), upper normal (23·0–24·9 kg/m²), overweight (25·0–29·9 kg/m²), and obese (≥30·0 kg/m²).[26] Given that the WHO BMI threshold recommendation for defining overweight among Asian populations is ≥23·0 kg/m²,[14] and since there is no standard nomenclature for the BMI range of more than 23·0 kg/m² to 24·9 kg/m², we classified this category as upper normal to assess the association between BMI and diabetes risk across the full range of BMIs in all geographical regions.

More granular obesity categories were considered in a prespecified supplementary analysis (appendix p 65).

Statistical analysis

Our analysis was restricted to individuals with complete data on the outcome (diabetes), exposure (BMI), and covariates (sex and age). Our analysis proceeded in four steps. First, we calculated generalised additive models of BMI as a continuous variable and the proportion of individuals with diabetes, stratified by sex and geographical region. We also stratified the generalised additive models by 10-year age groups to account for the different age structures of the geographical regions (appendix p 44). Generalised additive models allow for a non-linear association between exposure and outcome and generate smoothened plots. Second, we did multivariable Poisson regression analyses to examine the association between BMI as a continuous variable and diabetes, adjusted for age and stratified by sex, and present the resulting estimates as risk ratios (RRs). Univariate and logistic regression models were also estimated. Third, we used the same modelling approach as above, but included BMI as a categorical variable to allow for a granular assessment of the adjusted association between BMI and diabetes. We did all regression analyses in the whole pooled sample, and separately, stratified by geographical region and by country. All regression analyses included country fixed effects to account for unmeasured differences between countries, including data source (STEPS *vs* non-STEPS survey). Our data were modelled with a robust error structure, and SEs were adjusted for clustering at the primary sampling unit and country level. As a fourth and final step, we generated receiver operating characteristics (ROC) curves for BMI as a classifier for diabetes status by sex and geographical region. This analysis allowed us to compare the performance of BMI as a predictor of diabetes risk across regions, and to establish optimal binary cutoffs for a significantly greater risk of diabetes compared with a normal BMI. Optimal cutoffs were defined as the BMI value that maximises the Youden index (ie, the sum of sensitivity and specificity minus 1). We show sensitivity and specificity at optimal and additional binary BMI cutoffs (23 kg/m², 25 kg/m², and 30 kg/m²). In all regression and ROC analyses, we weighted each country equally. The rationale behind this equal weighting was to prevent surveys with a large sample size (particularly the India National Family and Health survey) from distorting the results for all geographical regions and the pooled sample. As such, the Indian survey contributed equally to the analysis, despite its large sample size. Descriptive statistics were calculated with sampling weights that we rescaled inversely to the sample size of the respective survey. Prespecified supplementary analyses were done with continuous biomarkers (ie, blood glucose or HbA_{1c}) as the outcome of interest (appendix p 69).

We subjected our results to several checks for robustness. First, given the large effect of age on diabetes status, we added quadratic and cubic terms in age to our main model to account for possible non-linearities in the association between age and diabetes (appendix pp 52, 63). Second, as socioeconomic status might influence diabetes risk independently of BMI,[17] in prespecified supplementary analyses, we also considered educational attainment (57 [98%] of 58 surveys; n=681 932) and household wealth quintiles (49 [84%] surveys; n=629 066) as covariates for the respective subsamples of countries with data on these variables, and added educational attainment and wealth quintiles to our main model (appendix pp 49, 50, 60–61). Further details on the construction and harmonisation of household wealth quintiles are provided in the appendix (p 35). Third, as an alternative to weighting countries equally, we ran our analysis with countries weighted proportional to their respective population size (appendix pp 54, 64). Fourth, although we did a complete-case analysis, we also provide a sensitivity analysis in which we imputed BMI, sex, and age (appendix p 47). Finally, we modified the specifications of our outcome variable by classifying individuals with a self-reported diabetes diagnosis but normal biomarker values (4456 [0·6%] of 685 616) as having diabetes (appendix pp 51, 62).

Statistical analyses were done using Stata version 15.0 and R version 3.5.1.

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

We identified 58 nationally representative surveys done in 57 LMICs, of which 49 were STEPS surveys and nine were non-STEPS surveys (table 1). Data on a diabetes biomarker were available in all 58 surveys. The diabetes biomarker used in 47 (81%) surveys was point-of-care fasting capillary glucose (appendix pp 33–34). Plasma equivalents were provided in all but eight of these surveys. For these eight surveys, we converted capillary glucose measurements to plasma glucose. No differences were observed in sensitivity analyses in which we assumed that all point-of-care glucose measuring devices had a built-in plasma equivalent (appendix pp 56, 66). We assumed that point-of-care fasting capillary glucose had been used in 12 (21%) surveys that did not provide details of the glucose measuring device used. For four (7%) surveys (Bangladesh, Costa Rica, Iraq, and Lebanon) a laboratory-based measurement of fasting plasma glucose was the only diabetes biomarker used. Only HbA_{1c} was available for four (7%) surveys (Fiji, Indonesia, Mexico, and South Africa), and five (9%) surveys (China, Guyana, Iran, Romania, and Seychelles) used both HbA_{1c} and fasting plasma glucose. No differences were observed in sensitivity analyses in which we assumed that participants with a missing fasting status were not fasting.

Department of Family and Preventive Medicine, School of Medicine (Prof M K Ali)**, Emory University, Atlanta, GA, USA**

Correspondence to:
Dr Jennifer Manne-Goehler, Medical Practice Evaluation Center, Massachusetts General Hospital, Harvard Medical School, Boston, MA 02114, USA
jmanne@partners.org

See **Online** for appendix

For the **NCD Microdata Repository** see https://extranet.who.int/ncdsmicrodata/index.php/catalog/STEPS

	Survey type	Survey year	Response rate	Sample size	Mean age (SD), years	Age range, years	Sex distribution*		Mean BMI (SD), kg/m²	Prevalence of diabetes
							Female	Male		
All countries	..	2009–19	86·2%	685 616	42·6 (12·6)	25–104	533 530 (77·8%; 52·8%)	152 086 (22·2%; 47·2%)	25·8 (6·1)	9·3%
Latin America and the Caribbean										
Chile	Non-STEPS	2009–10	85·0%	4049	47·7 (14·8)	25–100	2446 (60·4%; 51·8%)	1603 (39·6%; 48·2%)	28·0 (5·1)	9·7%
Costa Rica	STEPS	2010	87·8%	2234	47·1 (15·5)	25–104	1621 (72·6%; 50·4%)	613 (27·4%; 49·6%)	27·6 (6·0)	11·6%
Ecuador	STEPS	2018	69·5%	3337	44·6 (12·4)	25–69	1962 (58·8%; 51·7%)	1375 (41·2%; 48·3%)	27·9 (4·8)	9·1%
Guyana	STEPS	2016	66·7%	784	42·2 (11·9)	25–69	495 (63·1%; 53·0%)	289 (36·9%; 47·0%)	27·6 (6·8)	20·1%
Mexico	Non-STEPS	2009–12	90·0%	7002	54·3 (14·0)	25–99	3866 (55·2%; 66·6%)	3136 (44·8%; 33·4%)	28·8 (5·5)	34·4%
Saint Vincent and the Grenadines	STEPS	2013	67·8%	886	42·8 (12·2)	25–69	538 (60·7%; 56·9%)	348 (39·3%; 43·1%)	28·0 (6·3)	11·2%
Europe and central Asia										
Azerbaijan	STEPS	2017	Unknown	2325	43·0 (12·1)	25–69	1372 (59·0%; 50·6%)	953 (41·0%; 49·4%)	27·2 (5·1)	8·3%
Belarus	STEPS	2016	87·1%	4418	45·9 (12·5)	25–69	2584 (58·5%; 52·4%)	1834 (41·5%; 47·6%)	27·5 (5·3)	5·2%
Georgia	STEPS	2016	75·7%	2907	46·3 (12·7)	25–70	2113 (72·7%; 53·0%)	794 (27·3%; 47·0%)	29·0 (6·3)	6·4%
Kyrgyzstan	STEPS	2013	100·0%	2475	40·8 (11·5)	25–64	1562 (63·1%; 48·3%)	913 (36·9%; 51·7%)	26·6 (5·3)	5·4%
Moldova	STEPS	2013	83·5%	3231	43·8 (12·3)	25–69	2066 (63·9%; 50·6%)	1165 (36·1%; 49·4%)	27·5 (5·5)	7·0%
Mongolia	STEPS	2013	97·4%	1855	42·6 (9·1)	25–64	1044 (56·3%; 51·4%)	811 (43·7%; 48·6%)	27·2 (5·3)	4·7%
Romania	Non-STEPS	2015–16	69·1%	1775	51·6 (15·7)	25–80	931 (52·5%; 52·5%)	844 (47·5%; 47·5%)	28·7 (5·7)	11·3%
Tajikistan	STEPS	2016	94·0%	2155	36·4 (11·6)	25–70	1258 (58·4%; 43·2%)	897 (41·6%; 56·8%)	25·9 (4·7)	1·9%
East, south, and southeast Asia										
Bangladesh	STEPS	2018	84·6%	6155	41·9 (11·3)	25–69	3234 (52·5%; 52·6%)	2921 (47·5%; 47·4%)	23·0 (4·3)	9·6%
Bhutan	STEPS	2014	96·9%	2400	40·1 (11·2)	25–69	1444 (60·2%; 41·7%)	956 (39·8%; 58·3%)	24·2 (3·7)	2·5%
Cambodia	STEPS	2010	92·0%	5097	40·4 (10·8)	25–64	3311 (65·0%; 51·1%)	1786 (35·0%; 48·9%)	21·8 (3·3)	2·4%
China	Non-STEPS	2009	88·0%	8001	52·5 (13·8)	25–99	4282 (53·5%; 53·4%)	3719 (46·5%; 46·6%)	23·5 (3·5)	8·5%
India	Non-STEPS	2015–16	96·0%	490 532	37·0 (7·9)	25–54	417 843 (85·2%; 46·6%)	72 689 (14·8%; 53·4%)	22·8 (4·3)	4·9%
Indonesia	Non-STEPS	2014	83·0%	5345	44·4 (13·6)	25–101	2998 (56·1%; 51·9%)	2347 (43·9%; 48·1%)	23·6 (4·4)	8·1%
Laos	STEPS	2013	99·2%	2099	42·4 (10·8)	25–65	1268 (60·4%; 58·4%)	831 (39·6%; 41·6%)	23·1 (4·1)	5·6%
Myanmar	STEPS	2014	90·0%	7725	41·8 (11·0)	25–64	5028 (65·1%; 49·2%)	2697 (34·9%; 50·8%)	22·7 (4·5)	6·4%
Nepal	STEPS	2019	86·4%	4488	40·7 (12·4)	25–69	2850 (63·5%; 53·1%)	1638 (36·5%; 46·9%)	23·3 (4·1)	7·1%
Timor-Leste	STEPS	2014	96·3%	1993	44·4 (12·7)	25–69	1121 (56·2%; 56·2%)	872 (43·8%; 43·8%)	21·3 (3·9)	3·0%
Vietnam	STEPS	2015	79·8%	2763	42·8 (12·0)	25–69	1583 (57·3%; 50·6%)	1180 (42·7%; 49·4%)	22·3 (3·2)	3·1%
Sub-Saharan Africa										
Benin	STEPS	2015	98·6%	4032	39·0 (11·1)	25–69	2101 (52·1%; 53·7%)	1931 (47·9%; 46·3%)	23·4 (4·6)	6·6%
Botswana	STEPS	2014	63·0%	2559	39·2 (11·7)	25–69	1762 (68·9%; 48·7%)	797 (31·1%; 51·3%)	24·2 (5·8)	3·8%
Burkina Faso	STEPS	2013	97·8%	3935	39·3 (10·9)	25–64	1999 (50·8%; 53·1%)	1936 (49·2%; 46·9%)	22·4 (4·0)	2·8%
Comoros	STEPS	2011	96·5%	2359	41·5 (11·4)	25–64	1771 (75·1%; 73·9%)	588 (24·9%; 26·1%)	26·0 (5·9)	4·2%
Eritrea	STEPS	2010	97·0%	5518	43·5 (12·7)	25–74	3966 (71·9%; 80·8%)	1552 (28·1%; 19·2%)	20·4 (4·0)	3·6%
Eswatini	STEPS	2014	81·8%	1812	40·5 (12·1)	25–70	596 (32·9%; 56·0%)	1216 (67·1%; 44·0%)	27·3 (6·6)	6·6%
Kenya	STEPS	2015	95·0%	3287	39·1 (11·6)	25–69	1958 (59·6%; 50·5%)	1329 (40·4%; 49·5%)	23·6 (5·1)	2·4%
Lesotho	STEPS	2012	80·0%	1958	38·0 (11·0)	25–64	1307 (66·8%; 50·1%)	651 (33·2%; 49·9%)	25·8 (7·2)	2·8%
Liberia	STEPS	2011	87·1%	1,566	37·6 (10·0)	25–64	876 (55·9%; 54·0%)	690 (44·1%; 46·0%)	26·9 (7·4)	13·2%
Malawi	STEPS	2009	95·5%	2903	38·6 (11·0)	25–64	2043 (70·4%; 50·1%)	860 (29·6%; 49·9%)	23·1 (3·9)	0·9%
Namibia	Non-STEPS	2013	96·9%	3250	46·8 (8·3)	25–64	1906 (58·6%; 60·3%)	1344 (41·4%; 39·7%)	24·8 (6·2)	6·1%
Rwanda	STEPS	2012	99·0%	5214	38·6 (10·5)	25–64	3302 (63·3%; 53·2%)	1912 (36·7%; 46·8%)	22·6 (3·5)	1·6%
São Tomé and Príncipe	STEPS	2009	95·0%	1990	39·8 (11·3)	25–64	1157 (58·1%; 52·4%)	833 (41·9%; 47·6%)	24·7 (5·6)	2·9%
Seychelles	STEPS	2013	73·0%	1239	42·6 (10·5)	25–64	709 (57·2%; 49·9%)	530 (42·8%; 50·1%)	27·8 (6·0)	19·1%
South Africa	Non-STEPS	2012	92·6%	3201	43·8 (14·2)	25–97	2089 (65·3%; 52·9%)	1112 (34·7%; 47·1%)	27·7 (7·2)	13·2%
Sudan	STEPS	2015	88·0%	5273	40·0 (11·5)	25–70	3332 (63·2%; 46·1%)	1941 (36·8%; 53·9%)	23·7 (5·3)	8·4%
Tanzania	STEPS	2012	94·7%	4696	38·9 (10·8)	25–65	2519 (53·6%; 50·4%)	2177 (46·4%; 49·6%)	22·9 (4·7)	2·8%
Togo	STEPS	2010	91·0%	2567	38·9 (11·0)	25–64	1296 (50·5%; 51·6%)	1271 (49·5%; 48·4%)	23·5 (4·6)	3·3%

(Table 1 continues on next page)

	Survey type	Survey year	Response rate	Sample size	Mean age (SD), years	Age range, years	Sex distribution*		Mean BMI (SD), kg/m²	Prevalence of diabetes
							Female	Male		
(Continued from previous page)										
Uganda	STEPS	2014	99·0%	2562	40·2 (11·4)	25–69	1514 (59·1%; 56·9%)	1048 (40·9%; 43·1%)	22·9 (4·5)	1·7%
Zambia	STEPS	2017	74·0%	2534	39·2 (11·1)	25–69	1550 (61·2%; 50·1%)	984 (38·8%; 49·9%)	23·6 (5·0)	8·3%
Zanzibar	STEPS	2011	97·6%	2252	38·8 (10·1)	25–64	1412 (62·7%; 51·1%)	840 (37·3%; 48·9%)	24·3 (5·4)	3·5%
Middle East and north Africa										
Algeria	STEPS	2016	Unknown	5140	41·9 (11·6)	25–69	2823 (54·9%; 48·7%)	2317 (45·1%; 51·3%)	27·1 (5·4)	11·5%
Iran	STEPS	2016	99·0%	18 885	47·6 (14·7)	25–100	10 105 (53·5%; 54·1%)	8780 (46·5%; 45·9%)	27·1 (5·0)	11·3%
Iraq	STEPS	2015	93·0%	3166	42·6 (14·1)	25–102	1913 (60·4%; 48·2%)	1253 (39·6%; 51·8%)	29·5 (6·4)	18·9%
Lebanon	STEPS	2017	65·9%	1032	43·3 (11·4)	25–69	644 (62·4%; 51·9%)	388 (37·6%; 48·1%)	28·0 (5·4)	12·7%
Morocco	STEPS	2017	89·0%	4180	46·1 (14·9)	25–100	2717 (65·0%; 50·8%)	1463 (35·0%; 49·2%)	26·6 (5·3)	13·7%
Oceania										
Fiji	Non-STEPS	2009	80·0%	1324	55·5 (10·5)	25–90	757 (57·2%; 57·2%)	567 (42·8%; 42·8%)	29·0 (5·9)	42·8%
Kiribati	STEPS	2015	55·0%	956	43·1 (11·6)	25–69	538 (56·3%; 57·5%)	418 (43·7%; 42·5%)	30·7 (6·3)	20·9%
Marshall Islands	STEPS	2017	92·3%	2269	42·5 (12·1)	25–86	1221 (53·8%; 52·5%)	1048 (46·2%; 47·5%)	30·5 (6·8)	31·2%
Samoa	STEPS	2013	64·0%	1187	41·2 (10·9)	25–64	737 (62·1%; 49·9%)	450 (37·9%; 50·1%)	33·4 (7·4)	24·6%
Solomon Islands	STEPS	2015	58·4%	1467	41·5 (11·2)	25–71	798 (54·4%; 51·8%)	669 (45·6%; 48·2%)	27·3 (5·4)	5·4%
Tuvalu	STEPS	2015	76·0%	832	43·6 (12·4)	25–69	454 (54·6%; 45·9%)	378 (45·4%; 54·1%)	33·4 (6·7)	11·9%
Vanatu	STEPS	2011	94·0	4440	39·6 (10·9)	25–64	2218 (50·0%; 52·6%)	2222 (50·0%; 47·4%)	26·2 (5·6)	9·7%

Survey year and response rate shown for the complete study population of each survey. The remaining characteristics were calculated for individuals who met our inclusion criteria. Mean age, sex distribution, mean BMI, and prevalence of diabetes were calculated by use of rescaled sampling weights. Details of non-STEPS surveys included in the study are provided in the appendix (p 4). BMI=body-mass index. STEPS=Stepwise Approach to Surveillance. *Data are n (%; weighted %).

Table 1: **Characteristics of population-based surveys in 57 low-income and middle-income countries done in 2008–16, by geographical region**

The final pooled study sample included 685 616 individual participants (appendix p 5). The mean age of the overall sample was 42·6 years (SD 12·7; survey-specific age-ranges are included in the appendix [pp 6–32]); 533 530 (52·8%) were women and 152 086 (47·2%) were men (weighted sample). Overall, 99 602 (12·6%) participants were missing a glucose measurement, an additional 6734 (0·8%) were missing BMI measurements, and a further 678 (0·1%) were missing data on age or sex (total missingness of 13·5%). We found no differences in sociodemographic characteristics or BMI distribution among individuals with and without a glucose measurement (appendix p 39). Multiple imputation of BMI, sex, and age did not alter the main results (appendix p 47).

The average response rate across surveys was 86·2% (SD 12·0). Characteristics of the sample population (overall) and country-level demographic characteristics of all the surveys in the study sample are included in the appendix (pp 36–38). The proportion of survey respondents from rural areas was 53·9%, though data regarding rural–urban residence was only available in 38 (66%) of 58 surveys. Overall, the prevalence of overweight was 27·2% (95% CI 26·6–27·8), of obesity was 21·0% (19·6–22·5), and of diabetes was 9·3% (8·4–10·2). Compared with individuals without diabetes, a higher proportion of individuals with diabetes were overweight (134 412 [weighted percentage 26·8%] of 648 785 *vs* 12 334 [weighted percentage 31·6%] of 36 831; p<0·0001) and obese (55 180 [weighted

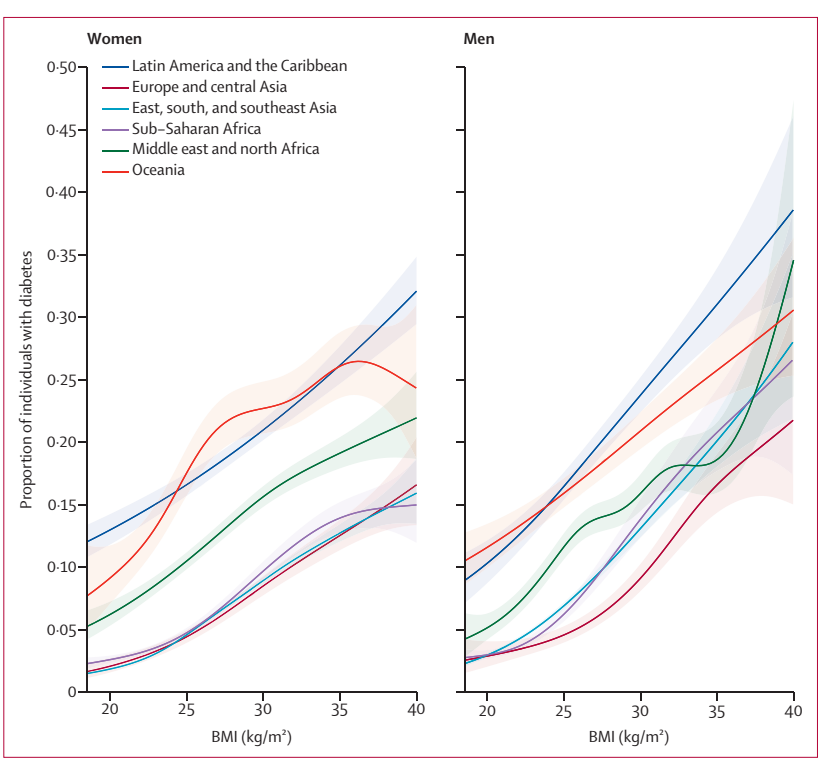


Figure 1: **Association between BMI and diabetes, stratified by sex and geographical region**
Generalised additive models of BMI and the proportion of women and men with diabetes. Grey areas represent 95% CIs. BMI=body-mass index.

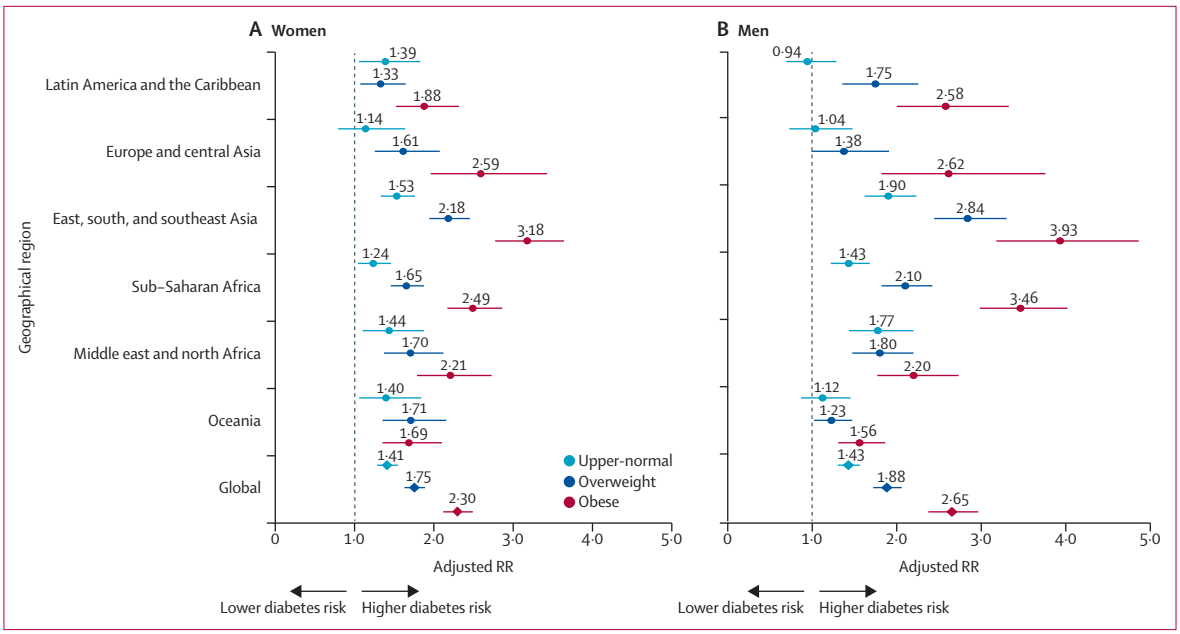


Figure 2: **Risk of diabetes in women (A) and men (B) stratified by BMI category and geographical region**
Adjusted RRs from multivariable Poisson regression models in the pooled sample and by geographical region are shown. The outcome was diabetes, according to measured biomarkers, and the exposure-measured BMI grouped into five categories: underweight (<18·5 kg/m²; not displayed), normal (18·5 kg/m² to <23 kg/m²; reference category), upper-normal (23 kg/m² to <25 kg/m²), overweight (25 kg/m² to <30 kg/m²), and obese (>30 kg/m²). All models controlled for age (in years) and included country-level fixed effects. Each country was weighted equally. Error bars represent 95% CIs. BMI=body-mass index. RR=risk ratio.

percentage 19·0%] *vs* 10 010 [weighted percentage 41·4%]; p<0·0001).

Generalised additive models of the association between BMI and diabetes, stratified by sex and geographical region, are shown in figure 1. The proportion of individuals with diabetes at any given BMI was generally greater for men than women, particularly at higher BMI values. The proportion of individuals with diabetes was generally highest at any given BMI in Latin America and the Caribbean and in Oceania for both men and women. When stratified by 10-year age categories, the proportion of individuals with diabetes generally increased with each increasing age category and was greatest in the age 54 years or older category for both sexes (appendix p 44). However, the proportion of individuals with diabetes who had a BMI of 30 kg/m² or higher rose steeply in the 25–34 age group for men in sub-Saharan Africa and across almost all regions in the 35 years and older age groups.

In the pooled sample across all 58 surveys, the risk of diabetes was higher in men than women (RR 1·05 [95% CI 1·04–1·06] *vs* 1·04 [1·03–1·04]; appendix p 45). Globally, when stratified by BMI category, the risk of diabetes in those in the upper-normal BMI category compared with the normal BMI category was 1·41 (1·28–1·55) in women and 1·43 (1·30–1·56) in men (figure 2). When stratified by BMI category and geographical region, the highest risk of diabetes among individuals in the upper normal BMI category compared with the normal BMI category was observed in east, south, and southeast Asia (1·90 [1·62–2·23] in men and 1·53 [1·33–1·76] in women) and in the Middle East and north Africa (1·77 [1·43–2·20] in men and 1·44 [1·10–1·88] in women; figure 2). The highest risk of diabetes among individuals in the overweight BMI category compared with the normal BMI category was observed in east, south, and southeast Asia (2·84 [2·44–3·30] in men and 2·18 [1·94–2·45] in women), in sub-Saharan Africa (2·10 [1·82–2·42]) in men, and in Oceania (1·71 [1·35–2·16]) in women. Compared with individuals in the normal BMI category, the highest risk of diabetes among individuals with obesity was observed in east, south, and southeast Asia (3·93 [3·18–4·86] in men and 3·18 [2·77–3·64] in women), in men in sub-Saharan Africa (3·46 [2·98–4·02]), and in women in Europe and central Asia (2·59 [1·96–3·43]). After stratifying the analyses by BMI with an additional category of 35 kg/m² or higher, the highest risk of diabetes was observed in women in east, south, and southeast Asia and in men in sub-Saharan Africa (appendix p 65). Sensitivity analyses including age polynomials, adjustment for education and wealth, classification of individuals with a self-reported diabetes diagnosis but normal biomarker values as having diabetes, and use of sample weights proportional to the population size of each country did not appreciably change the results (appendix pp 49–52, 54, 60–64). In country-level, sex-stratified multivariable Poisson regression models, with BMI as a continuous variable, the highest risk of diabetes for each 1 kg/m² gain in BMI

was observed in women in Bhutan (1·16 [1·10–1·24]) and in men in Cambodia (1·19 [1·11–1·29]; appendix p 42).

ROC curves for BMI and diabetes risk, according to sex and geographical region are shown in figure 3. East, south, and southeast Asia, eastern Europe and central Asia, and sub-Saharan Africa had the largest area under the receiver operating characteristic curves. The ROC-derived BMI cutoffs for diabetes screening, according to sex and geographical region, are shown in table 2. Optimal BMI cutoffs, as estimated by maximising the Youden index, were lowest in women (23·9 kg/m²) and men (23·8 kg/m²) in east, south, and southeast Asia, and in men (24·2 kg/m²) in the Middle East and north Africa. BMI cutoffs were highest in women (28·3 kg/m²) in Latin America and the Caribbean and in the Middle East and north Africa, and in men (28·1 kg/m²) in Oceania.

Discussion

In this cross-sectional study of 685 616 individuals across 57 LMICs, we found that a greater risk of diabetes was observed at a BMI of 23 kg/m² or higher, with a corresponding increase in diabetes risk of 43% in men and 41% in women when compared with those who have a BMI of 18·5–22·9 kg/m². ROC analyses showed variability across sex and geographical regions in the BMI cutoffs at which sensitivity and specificity were optimised for diabetes screening, ranging from a BMI cutoff of 23·8 kg/m² in men in east, south, and southeast Asia to a BMI of 28·3 kg/m² in women in the Middle East and north Africa and in Latin America and the Caribbean. Given that diabetes remains a major challenge for LMICs to reduce premature mortality from non-communicable diseases (Sustainable Development Goal 3.4),[26] our findings offer an important insight to inform context-specific diabetes screening guidelines.

We also found differences in the risk of diabetes across BMI categories in several regions, particularly among men. For instance, men and women in sub-Saharan Africa and east, south, and southeast Asia had more than a 100% increase in the risk of diabetes between the overweight and the obesity category. Additionally, although the prevalence of diabetes increased with older age, the proportion of individuals with diabetes increased steeply across all regions in the 35–44 age group, as well as among men aged 25–34 years in sub-Saharan Africa. These findings are consistent with accumulating evidence suggesting that the prevalence of metabolic syndrome is increasing rapidly among younger adults aged 25–44 years in LMICs.[27] Although current WHO guidelines[28] recommend diabetes screening of asymptomatic adults aged older than 40 years and in those with a BMI of 25 kg/m² or higher, our findings suggest that diabetes testing in individuals aged younger than 40 years in specific LMIC contexts should be considered to implement targeted and timely efforts aimed at reducing the long-term complications associated with diabetes.

Previous research has shown that the largest loss in the diabetes care continuum in LMICs is at the stage of diagnosis.[18] However, efforts to improve diagnosis remain a substantial challenge in resource-limited settings due, in part, to a paucity of clear evidence about which individuals should be screened, and to the need

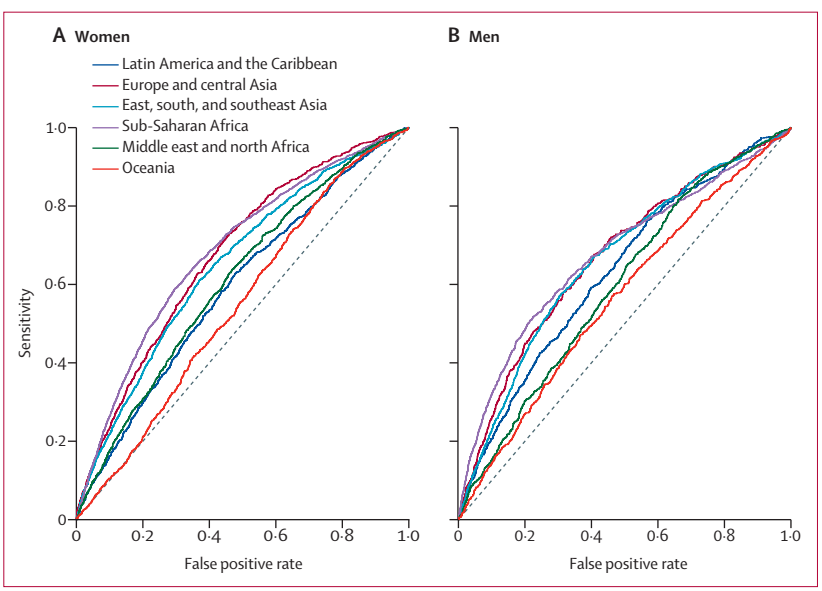


Figure 3: **Receiver operating characteristic curves of body-mass index and diabetes risk, stratified by sex and geographical region**
Each country was weighted equally.

	AUC	Sensitivity	Specificity	Youden index
Latin America and the Caribbean				
BMI cutoff in women, kg/m²	0·59	..	..	..
28·3 (optimal)	..	62·8%	52·1%	15·0%
23·0	..	91·5%	15·2%	6·7%
25·0	..	80·7%	28·0%	8·6%
30·0	..	49·4%	63·6%	13·1%
BMI cutoff in men, kg/m²	0·63	..	..	..
25·3 (optimal)	..	76·3%	43·2%	19·5%
23·0	..	87·5%	22·6%	10·0%
25·0	..	78·0%	40·6%	18·6%
30·0	..	34·0%	81·2%	15·2%
Europe and central Asia				
BMI cutoff in women, kg/m²	0·68	..	..	..
28·0 (optimal)	..	73·0%	54·0%	27·0%
23·0	..	93·4%	19·7%	13·1%
25·0	..	87·1%	33·3%	20·4%
30·0	..	59·3%	66·0%	25·2%
BMI cutoff in men, kg/m²	0·67	..	..	..
27·6 (optimal)	..	67·7%	59·1%	26·7%
23·0	..	90·6%	20·1%	10·6%
25·0	..	81·8%	36·5%	18·3%
30·0	..	48·7%	76·4%	25·1%

(Table 2 continues on next page)

	AUC	Sensitivity	Specificity	Youden index
(Continued from previous page)				
East, south, and southeast Asia				
BMI cutoff in women, kg/m²	0·65	..	..	..
23·9 (optimal)	..	61·0%	63·0%	24·1%
23·0	..	68·1%	54·2%	22·3%
25·0	..	50·5%	71·3%	21·8%
30·0	..	15·8%	93·8%	9·6%
BMI cutoff in men, kg/m²	0·66	..	..	..
23·8 (optimal)	..	57·1%	69·6%	26·6%
23·0	..	63·9%	62·1%	26·0%
25·0	..	42·3%	79·9%	22·2%
30·0	..	8·5%	97·0%	5·5%
Sub-Saharan Africa				
BMI cutoff in women, kg/m²	0·68	..	..	..
27·3 (optimal)	..	58·9%	70·4%	29·3%
23·0	..	80·1%	42·7%	22·8%
25·0	..	70·1%	57·5%	27·7%
30·0	..	43·8%	81·0%	24·8%
BMI cutoff in men, kg/m²	0·68	..	..	..
25·4 (optimal)	..	50·9%	78·4%	29·3%
23·0	..	67·2%	59·4%	26·6%
25·0	..	52·3%	76·4%	28·8%
30·0	..	22·2%	94·0%	16·2%
Middle East and north Africa				
BMI cutoff in women, kg/m²	0·61	..	..	..
28·3 (optimal)	..	63·8%	53·0%	16·9%
23·0	..	92·4%	16·6%	9·0%
25·0	..	83·2%	29·5%	12·6%
30·0	..	50·3%	64·4%	14·7%
BMI cutoff in men, kg/m²	0·60	..	..	..
24·2 (optimal)	..	81·7%	33·8%	15·5%
23·0	..	88·7%	24·1%	12·9%
25·0	..	72·9%	40·2%	13·1%
30·0	..	30·7%	79·4%	10·2%
Oceania				
BMI cutoff in women, kg/m²	0·55	..	..	..
25·2 (optimal)	..	85·5%	23·8%	9·3%
23·0	..	93·3%	13·2%	6·5%
25·0	..	86·0%	22·8%	8·8%
30·0	..	58·0%	48·2%	6·3%
BMI cutoff in men, kg/m²	0·56	..	..	..
28·1 (optimal)	..	57·1%	53·7%	10·8%
23·0	..	87·6%	17·0%	4·7%
25·0	..	76·4%	31·2%	7·5%
30·0	..	43·6%	65·7%	9·3%

Table shows AUCs and diabetes screening characteristics (sensitivity, specificity, and Youden index) of several binary BMI cutoffs for diabetes risk for each geographical region and by sex. Optimal BMI cutoffs were defined as the respective BMI value that maximises the Youden index. Each country was weighted equally. AUC=area under the receiver operating characteristic curve. BMI=body-mass index.

***Table 2*: BMI cutoffs for diabetes risk in 57 low-income and middle-income countries, according to geographical region and sex**

to balance efforts to increase screening and diagnosis with investments that are needed to strengthen diabetes care delivery. Our analysis provides the first empirical evidence base regarding the trade-off between sensitivity and specificity when choosing a BMI-based threshold for diabetes screening across a large sample of LMICs. Although lower BMI cutoffs for the detection of metabolic risk have been recommended for Asian populations compared with all other populations globally,[14] which is consistent with our findings, we found similar results in other geographical regions, such as the Middle East and north Africa. Secondly, the observation that the proportion of individuals with diabetes who had a BMI of 30 kg/m² or greater increased in populations aged younger than 40 years in particular regions suggests that any development of screening strategies for diabetes might require not only revisiting existing BMI cutoffs, but also the inclusion of younger populations than is currently recommended in most guidelines. Finally, we found that BMI performed modestly overall as a single criterion for determining which individuals to screen for diabetes. Given this finding, other low-cost anthropometric measures, such as waist circumference,[29] might be explored to further optimise assessment of metabolic risk in these settings.[30]

Our study has several limitations. First, defining so-called optimal binary BMI cutoffs allows the general suitability of BMI as a single predictor of diabetes status (eg, in the context of diabetes screening) to be compared between geographical regions. However, although BMIs that maximise the Youden index consider sensitivity and specificity equally, policy makers searching for optimal BMI cutoffs for diabetes screening might attribute higher priority to either sensitivity or specificity and need to take further context-specific factors into account. Second, the definition of biochemical diabetes was limited to a single glucose measurement in some countries, and was based on capillary glucose measurement in most surveys. These measures can either overestimate or underestimate the true prevalence of diabetes.[31] Although we applied the International Federation of Clinical Chemistry's recommendation on the conversion of capillary glucose to plasma equivalents,[22] this conversion does not eliminate the possibility of inaccuracy due to underlying haematocrit abnormalities, which could be particularly relevant in contexts in which anaemia or other haematological disorders are highly prevalent. Third, the definition of diabetes was heterogeneous given the absence of a standardised biochemical measurement of diabetes across all surveys. Fourth, although we provide BMI cutoffs for diabetes risk, it is important to note that the BMI in individuals with diabetes at the time of the survey could have been influenced by weight gain or weight loss associated with diabetes itself or with medications to treat diabetes. However, studies in other contexts suggest that weight change during the first

2 years following a diagnosis of type 2 diabetes is modest.[32] Additionally, given that only 15 493 (3·3%) of 685 616 individuals in this study were on pharmacological treatment for diabetes, weight fluctuations attributable to diabetes medications seem to be a less probable cause for concern in this study population. This assertion is further supported by a sensitivity analysis, which limited the outcome of interest to those with untreated diabetes (appendix pp 57, 67). Fifth, guidelines about optimal bodyweight should not only be informed by risk of metabolic diseases, but also by cardiovascular and other obesity-associated conditions and mortality, which were not considered in this analysis. Finally, given the observational and cross-sectional design of our study, we report correlation and not causation; although, there is strong biological evidence for a positive association between BMI and diabetes risk.

The alarming rise in the prevalence of overweight, obesity, and diabetes in LMICs is an imminent health crisis that requires urgent population-level strategies to reverse current and projected trends. In this study of 57 LMICs, we show substantial regional variability in the association between BMI and diabetes risk and provide suggested sex-stratified and region-stratified BMI cutoffs for diabetes risk when used as a sole anthropometric measurement to identify which individuals should be screened for diabetes. Our findings underscore the importance of context-dependent studies in LMICs to inform clinical practice and patient-centred decision making.

Contributors

JM-G, JAS, and FT conceptualised the study. JM-G, PG, MEM, CE, MT, TWB, RA, JID, and SV led the data curation. FT led the statistical analysis with assistance from MT. JM-G, TWB, RA, SV, and PG participated in funding acquisition. JAS, FT, JM-G, and DJW wrote the first draft of the manuscript and all authors provided important inputs on multiple iterations. All authors have approved the final version. JM-G is the guarantor of the work. All authors had full access to all the data in the study and had final responsibility for the decision to submit for publication. FT, JAS, MT, and JM-G have accessed and verified the study data.

Declaration of interests

MKA reports receiving a grant from Merck and Co awarded to Emory University, outside the submitted work. DJW reports serving on a data monitoring committee for Novo Nordisk SOUL and FLOW trials. JBM reports serving as an academic associate for the American clinical laboratory, Quest Diagnostics. All other authors declare no competing interests.

Data sharing

Deidentified participant-level data used in this study are publicly available and can be obtained on request or via the weblinks provided in the appendix (p 70). The STROBE checklist can also be accessed on request. In addition, data dictionaries will be shared by the corresponding author on request.

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