Diabetes Prevalence and Its Relationship With Education, Wealth, and BMI in 29 Low- and Middle-Income Countries

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OBJECTIVE

Diabetes is a rapidly growing health problem in low- and middle-income countries (LMICs), but empirical data on its prevalence and relationship to socioeconomic status are scarce. We estimated diabetes prevalence and the subset with undiagnosed diabetes in 29 LMICs and evaluated the relationship of education, household wealth, and BMI with diabetes risk.

RESEARCH DESIGN AND METHODS

We pooled individual-level data from 29 nationally representative surveys conducted between 2008 and 2016, totaling 588,574 participants aged ≥25 years. Diabetes prevalence and the subset with undiagnosed diabetes was calculated overall and by country, World Bank income group (WBIG), and geographic region. Multivariable Poisson regression models were used to estimate relative risk (RR).

RESULTS

Overall, prevalence of diabetes in 29 LMICs was 7.5% (95% CI 7.1–8.0) and of undiagnosed diabetes 4.9% (4.6–5.3). Diabetes prevalence increased with increasing WBIG: countries with low-income economies (LICs) 6.7% (5.5–8.1), lower-middle-income economies (LMIs) 7.1% (6.6–7.6), and upper-middle-income economies (UMIs) 8.2% (7.5–9.0). Compared with no formal education, greater educational attainment was associated with an increased risk of diabetes across WBIGs, after adjusting for BMI (LICs RR 1.47 [95% CI 1.22–1.78], LMIs 1.14 [1.06–1.23], and UMIs 1.28 [1.02–1.61]).

CONCLUSIONS

Among 29 LMICs, diabetes prevalence was substantial and increased with increasing WBIG. In contrast to the association seen in high-income countries, diabetes risk was highest among those with greater educational attainment, independent of BMI. LMICs included in this analysis may be at an advanced stage in the nutrition transition but with no reversal in the socioeconomic gradient of diabetes risk.

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EPIDEMIOLOGY/HEALTH SERVICES RESEARCH

Diabetes is a rapidly growing health problem in low- and middle-income countries (LMICs), where the rate of increase in prevalence over the past two decades has surpassed that of high-income countries (1). An estimated three in four people with diabetes currently reside in an LMIC, where the vast majority are thought to be undiagnosed (2). While there is an urgent need for effective population-level strategies to halt the growing burden of this disease, an important limitation to understanding the impact of diabetes in LMICs is a lack of robust empirical data on diabetes prevalence and its relationship with socioeconomic status (SES) across varying levels of economic development (3–5). Although estimates of diabetes prevalence in LMICs are available (1,2), a major limitation of the existing literature is its inability to identify those at highest risk of diabetes based on key individual-level socioeconomic characteristics. Given that diabetes prevalence, its associated complications, and related mortality are thought to be strongly related to SES (6,7), understanding the relationship between SES and diabetes can inform health system strategies to improve the prevention and management of diabetes and direct interventions toward the highest-risk populations (8). Yet, despite a vast literature on the relationship between SES and diabetes in high-income countries (9,10), few studies to date have explored this association in LMICs (5,11).

Unlike well-characterized biological risk factors for diabetes, such as older age and higher BMI, the relationship between SES and diabetes may differ across countries at varying levels of economic development (11). In high-income countries, diabetes tends to be more prevalent among populations with lower SES (9,12), with some studies showing that this relationship is mainly but not solely driven by overweight and obesity (13,14). In contrast, in low-income countries, diabetes is thought to be more prevalent among affluent groups, although this finding has been inconsistent and limited by lack of individual-level data (11,15).

A complex interplay of economic, demographic, and epidemiologic changes associated with large shifts in dietary and physical activity patterns, known as the nutrition transition, have been proposed as primary drivers of the alarming rise in obesity and diabetes in LMICs (16). Within this framework, and the recently proposed obesity transition theory (17), unhealthy lifestyle behaviors are first adopted by more affluent groups. As public knowledge of disease prevention and access to preventive services increase, social norms change, and the rise of obesity and diabetes in affluent groups is attenuated and the burden shifts to vulnerable segments of the population (17,18). As such, an understanding of the relationship between SES and diabetes risk in the context of a dynamic socioeconomic gradient can help identify those at highest risk of diabetes and guide policies to prevent, diagnose, and treat this disease. In this study, we *1*) estimate diabetes prevalence overall and by country, geographic region, and World Bank income group (WBIG) based on individual-level data from 29 LMICs and *2*) explore the relationship of diabetes with SES and BMI with measures of individual educational attainment and household wealth in these 29 LMICs.

RESEARCH DESIGN AND METHODS

Data Sources

We performed a pooled analysis of individual-level data from 29 nationally representative population-based surveys in LMICs. The requirements for inclusion of a national survey as well as the search methods have been described previously (19). Further details specific to this analysis are provided in Supplementary Data. Briefly, the requirements for inclusion in this study of a country survey were as follows: the survey *1*) was conducted during or after 2008, *2*) had data available at the individual level, *3*) was conducted in countries with low-income economies (LICs), lower-middle-income economies (LMIs), or upper-middle-income economies (UMIs) according to the WBIG at the time the survey was conducted (20), *4*) was nationally representative, *5*) had a response rate $\geq$50%, and *6*) contained a diabetes biomarker (either a glucose measurement or hemoglobin A_{1c} [HbA_{1c}]).

Search Methodology

We first identified all countries in which a World Health Organization (WHO) STEPwise approach to Surveillance (STEPS) survey had been conducted during a

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year in which the country fell into an eligible World Bank income category. The STEPS survey is a standardized instrument for collecting and disseminating data about noncommunicable disease risk factors in adults living in WHO member countries (21). We systematically contacted and requested data from each eligible post-2007 STEPS survey listed on the WHO website (22). Ultimately, we included 19 STEPS surveys (Supplementary Data). For eligible LMICs that did not have a STEPS survey, lacked valid contact information, or declined our request for data (97 countries total), we performed a systematic Google search and identified 35 potentially eligible non-STEPS surveys. We ultimately included data from 10 countries in the analysis (Supplementary Data). Country categories and country-specific sampling methods for these surveys are provided in Supplementary Data.

Diabetes Biomarkers

The diabetes biomarker used in 21 of the 29 included surveys was a point-of-care fasting capillary glucose (Supplementary Data). Plasma equivalents were provided by all but eight of these surveys. For these eight, we multiplied capillary glucose values by 1.11 so that all values were reported in plasma equivalents. This adjustment was based on published guidelines and evidence that has shown that capillary glucose often underestimates plasma glucose levels (1,23,24). For 5 of the 29 study surveys, a laboratory-based measurement of fasting plasma glucose was the diabetes biomarker. For the remaining three surveys, only HbA_{1c} was available (Fiji, Indonesia, and South Africa). Where fasting status of participants was unreported, fasting was assumed because all but one survey protocol requested fasting status. The exception was the India National Family Health Survey (NFHS), where participants were not instructed to fast and nonfasting state was assumed in the primary analysis. We also performed a sensitivity analysis in which we assumed all participants who were missing data on fasting status to be nonfasting (Supplementary Data).

Definitions of Diabetes

Presence of diabetes was determined based on the current WHO diagnostic thresholds as any of the following: a fasting plasma glucose $\geq$7.0 mmol/L (126 mg/dL), a random plasma glucose $\geq$11.1 mmol/L (200 mg/dL), or, in the case of Fiji, Indonesia, and South Africa, an HbA_{1c} measurement of $\geq$6.5% (25). Undiagnosed diabetes was defined by meeting the above biochemical criteria in participants who self-reported no prior diabetes diagnosis. Individuals reporting use of drugs for blood glucose control were also classified as having diabetes, irrespective of the biomarker values. Respondents who self-reported a diagnosis of diabetes but were not on diabetes medications and did not meet the biomarker diagnostic criteria were not classified as having diabetes (N = 2,403 [0.44% of the overall sample]). We excluded participants younger than 25 years old for two main reasons. First, the focus of the study was adults with type 2 diabetes, the vast majority of whom are assumed to develop this disease after age 20 years (26). Secondly, 25 years of age or older was the minimum age of inclusion for many of the surveys used in this analysis. Survey-specific age ranges are included in Supplementary Data. Total diabetes (hereafter "diabetes") includes all respondents meeting criteria for diabetes; undiagnosed diabetes is presented as a subset of total diabetes.

BMI, Individual Educational Attainment, and Household Wealth

Height and weight were measured in all the surveys included in this analysis. We defined BMI as weight measured in kilograms divided by the square of height in meters and classified BMI as underweight (<18.5 kg/m^2), normal weight (18.5 to <25.0 kg/m^2), overweight (25.0 to <30.0 kg/m^2), or obese ($\geq$30.0 kg/m^2) (27). Educational attainment was denoted as no formal schooling, less than primary school or primary school completed (less than or up to grade 6 completed), and secondary school (grade 7–12) or above. When available, local education categorical variables were used to classify all participants according to these categories; when local education categorical variables were not available, we used years of education completed (a continuous variable). For household wealth, wealth quintiles were constructed based on a combination of four different measures of wealth: continuous income, income categories, income quintiles, or an asset index (Supplementary Data).

WBIG Classification

Each country was categorized according to the WBIG classification, which sorts countries by gross national income and is calculated and published annually using the World Bank Atlas method (28). For our analysis, we categorized each country according to the WBIG published in the year the survey was performed. For detailed WBIG and geographic classifications, please see Supplementary Data.

Statistical Analysis

We estimated the prevalence of diabetes and the subset with undiagnosed diabetes among adults 25 years of age and older overall and for each country, geographic region, and WBIG. We then performed analyses to estimate prevalence of diabetes and undiagnosed diabetes by BMI, educational attainment, and household wealth quintile. Analyses were performed using Stata, version 14.2 (College Station, TX) with point estimates and variance taking into account the survey design. When available, sample weights corresponding to the biomarker examination (e.g., subsample weights) were used. When sample weights were missing for an observation within a country, the mean sample weight for all observations in that country was assigned. For estimates (including regression analyses) that included more than one country, sampling weights were scaled such that each country contributed proportionally to its population size.

Poisson regression models with country-level fixed effects and SEs adjusted for clustering at the country level were used to evaluate the relationship between educational attainment, household wealth, and diabetes overall by country, WBIG, and geographic region. Regression models were adjusted for age, sex, BMI, educational attainment, and household wealth quintile, as defined above. We used restricted cubic splines with five knots (5th, 27.5th, 50th, 72.5th, and 95th percentiles) for age in all regressions to avoid loss of information due to categorization of this continuous variable. Burkina Faso, Chile, Costa Rica, and Fiji were dropped from multivariable prediction models due to a lack of data on household wealth. Though the Seychelles survey collected income data, a harmonized wealth quintile was not available at the time of this analysis, so Seychelles was also excluded from the

Table 1—Characteristics of population-based surveys conducted in 29 LMICs between 2008 and 2016, by World Bank income classification

Country*	Year†	Response rate (%)‡	Sample size§	Mean age (years)	Female (%)
UMIs					
Chile	2009/2010	85	4,149	51	60.5
China	2009	88	8,120	52.5	53.2
Costa Rica	2010	87.8	2,433	51.6	73.1
Ecuador	2012	81.5	9,132	37.2	69.4
Fiji	2009	80	1,344	55.5	57.1
Guyana	2016	66.7	702	45.2	63.3
Namibia	2013	96.9	3,244	47	58.1
Romania	2015/2016	69.1	1,774	51.6	52.5
Seychelles	2013	73	1,240	45.7	57.2
South Africa	2012	92.6	3,390	48.5	65.2
Saint Vincent and the Grenadines	2013	67.8	889	46.2	60.7
Total	—	80.8	36,417	48.4	60.9
LMIs					
Bhutan	2014	96.9	2,408	42.6	60.1
Georgia	2016	75.7	2,973	50.7	72.4
India	2015/2016	96	498,137	36.1	85.1
Indonesia	2014/2015	83	5,350	49	55.8
Kenya	2015	95	3,325	41.4	59.5
Mongolia	2009	95	1,420	41.3	38.5
Swaziland	2014	81.8	2,044	43.6	67.2
Timor-Leste	2014	96.3	2,021	44.4	56.5
Total	—	90	524,983	44.5	60.5
LICs					
Bangladesh	2011	98 F; 92 M	7,305	51.3	49.7
Benin	2008	99	3,510	43.3	51.0
Burkina Faso	2013	97.8	3,945	39	50.7
Comoros	2011	96.5	2,295	41.7	73.9
Liberia	2011	87.1	2,121	39	56.5
Nepal	2013	98.6	3,286	44	68.3
Tanzania	2012	94.7	4,628	42.2	52.2
Togo	2010	91	2,582	39.5	50.5
Uganda	2014	99	2,633	40.2	59.3
Zanzibar	2011	97.6	2,174	41.1	61.3
Total	—	92.8	27,174	41	58.2
Overall total‖			588,574	45.0	50.4

F, female; M, male. *Country classification at time of survey according to World Bank gross national income per capita in USD (Atlas methodology). Available from https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-worldbank-country-and-lending-groups. †Year in which data collection for the survey took place. ‡Response rate for questionnaire/interview. §Number of participants with nonmissing diabetes biomarker, nonpregnant, and aged ≥25 years. Unweighted. ‖Values for overall total are weighted, accounting for complex sampling design. Country-level values are unweighted.

regression models. Since <20% of participants were missing data for each variable of interest, we conducted a complete-case analysis. The number of participants with missing data on each sociodemographic variable included in this analysis is provided in Table 2.

RESULTS

Survey and Sample Characteristics

The survey characteristics by WBIG are summarized in Table 1. The final study sample included 588,574 individual participants in 29 LMICs. The mean age of the overall sample was 45.0 years; 50.4% of the respondents were female. Characteristics of the sample population with diabetes and the subset with undiagnosed diabetes can be found in Table 2. The pooled data set of participants included 32,634 individuals with diabetes, among whom 20,197 had undiagnosed diabetes (Table 2).

Prevalence of Total Diabetes

The overall prevalence of diabetes among adults 25 years or older across these 29 countries was 7.5% (95% CI 7.1–8.0) (Supplementary Data). The country-level prevalence of diabetes and prevalence of undiagnosed diabetes across these surveys, categorized by WBIG, are summarized in Fig. 1. Age-adjusted country-level prevalence estimates with 95% CI are presented in Supplementary Data. When countries were stratified by WBIG, the overall prevalence of diabetes increased with increasing income group (LICs 6.7% [95% CI 5.5–8.1], LMIs 7.1% [95% CI 6.6–7.6], and UMIs 8.2% [95% CI 7.5–9.0%) (Fig. 1 and Supplementary Data). A similar trend was observed when countries were stratified by BMI and WBIG, with diabetes prevalence among participants with obesity of 11.1% in LICs (95% CI 8.5–14.4), 14.4% in LMIs (95% CI 13.4–15.5), and 21.2% in UMIs (95% CI 17.0–26.2) (Supplementary Data).

When stratified by geographic region, diabetes prevalence for the overall sample was lowest in the group of surveys from Sub-Saharan Africa (5.2% [95% CI 4.0–6.7]) and highest in the group of surveys from the Middle East and Central Asia (12.8% [95% CI 10.9–15.1])

Table 2—Characteristics of participants in population-based surveys conducted in 29 LMICs between 2008 and 2016

	Without diabetes	Total diabetes	Undiagnosed diabetes*
N	555,940	32,634	20,197
Sex			
Male	49.3 (103,462)	54.4 (7,752)	56.0 (4,824)
Female	50.7 (452,474)	45.6 (24,882)	44.0 (15,373)
Missing	4	0	0
Age-group (years)			
25–44	55.6 (435,163)	36.8 (18,963)	42.4 (13,188)
45–54	22.8 (100,779)	28.9 (10,201)	26.6 (5,491)
≥55	21.6 (19,998)	34.3 (3,470)	31.0 (1,518)
Missing	0	0	0
BMI classification†			
Underweight	11.1 (83,149)	5.5 (2,084)	6.6 (1,487)
Normal weight	60.8 (325,538)	44.9 (11,777)	47.7 (7,203)
Overweight	22.4 (107,938)	35.0 (8,820)	32.2 (4,674)
Obese	5.8 (37,058)	14.6 (5,589)	13.4 (2,740)
Missing	2,257	4,364	4,093
Educational attainment‡			
No formal schooling	20.2 (187,845)	18.3 (8,778)	19.6 (6,068)
Primary school	25.1 (94,385)	26.2 (5,900)	27.5 (3,423)
Secondary school or above	54.7 (271,211)	55.5 (17,561)	52.9 (10,561)
Missing	2,499	395	145
Household wealth quintile§			
1 (poorest)	17.2 (102,739)	14.9 (3,609)	17.7 (2,664)
2	19.3 (112,132)	13.6 (4,353)	14.1 (2,981)
3	20.7 (112,368)	17.9 (5,511)	18.5 (3,592)
4	21.1 (107,267)	23.8 (7,495)	23.0 (4,497)
5 (richest)	21.6 (104,364)	29.8 (9,456)	26.8 (5,432)
Missing	17,070	2,211	1,031

Data are weighted percent (unweighted *n*); percent accounts for sampling design. "Missing" value is unweighted *n*. *Undiagnosed diabetes corresponds to a subset of the total diabetes population. †BMI classification: underweight (<18.5 kg/m^2), normal weight (18.5 to <25.0 kg/m^2), overweight (25.0 to <30.0 kg/m^2), or obese (≥30.0 kg/m^2). ‡Educational attainment categories: no formal schooling, less than primary school or primary school completed (less than or up to grade 6 completed), and secondary school (grades 7–12) or above. §Household wealth quintiles were constructed based on a combination of four different measures of wealth: continuous income, income categories, income quintiles, or an asset index (Supplementary Data).

(Supplementary Data). Diabetes prevalence increased with higher BMI, with a prevalence among participants with obesity of 9.2% in the group of surveys from Sub-Saharan Africa (95% CI 7.1%–11.9), 14.4% in Latin America and the Caribbean (95% CI 12.4–16.7), 17.7% in Southeast Asia and Pacific (95% CI 15.5–20.1), and 20.0% in the Middle East and Central Asia (95% CI 17.5–22.9) (Supplementary Data). Additional unadjusted analyses stratified by educational attainment and household wealth quintile according to WBIG are provided in Supplementary Data.

Prevalence of Undiagnosed Diabetes

The overall prevalence of undiagnosed diabetes was 4.9% (95% CI 4.6–5.3) (Supplementary Data). The prevalence of undiagnosed diabetes largely mirrored trends for the total population with diabetes and increased with ascending income group (Fig. 1 and Supplementary Data). When stratified by geographic region, the prevalence of undiagnosed diabetes estimated for surveys from each of the four geographic regions was as follows: 3.1% in the Middle East and Central Asia (24.2% of the total diabetes regional proportion), 3.2% for Sub-Saharan Africa (62.3% of the total diabetes regional proportion), 3.6% for Latin America and the Caribbean (41.9% of the total diabetes regional proportion), and 5.1% for Southeast Asia and Pacific (66.3% of the total diabetes regional proportion) (Supplementary Data).

Relationship of Educational Attainment and BMI With Prevalent Diabetes

Associations of educational attainment and BMI with diabetes are summarized in Table 3. Overall, greater educational attainment compared with no formal schooling was associated with greater diabetes risk after adjustment for age, sex, and wealth quintile: relative risk (RR) 1.36 (95% CI 1.22–1.52) for secondary school or above compared with no formal schooling. The association was slightly attenuated after adjustment for BMI but remained statistically significant, with a 24% increase in the risk of diabetes for those with secondary school or higher compared with those with no formal education.

When countries were stratified by WBIG and after adjustment for age, sex, and wealth quintile, there was a statistically significant association between higher educational attainment and diabetes risk compared with no formal education (Table 3). This association was maintained across WBIGs after adjustment for BMI, albeit slightly attenuated. When compared with no formal education, secondary or above schooling was positively associated with diabetes risk (LICs RR 1.47 [95% CI 1.22–1.78], LMIs RR 1.14 [95% CI 1.06–1.23], and UMIs RR 1.28 [95% CI 1.02–1.61]). After adjustment for age, sex, wealth, and education, the association between BMI and diabetes risk was robust and increased with WBIG. Compared with participants with a normal BMI, participants with obesity had an RR of 1.54 (95% CI 1.24–1.91) in LICs, 2.64 (95% CI 2.37–2.95) in LMIs, and 3.45 (95% CI 2.77–4.30) in UMIs (Table 3).

Relationship of Household Wealth and Prevalent Diabetes

Overall, in the fully adjusted models, we found a statistically significant association between diabetes and the highest wealth quintile, RR 1.19 (95% CI 1.03–1.36), compared with the lowest wealth quintile (Supplementary Data). With stratification by WBIG, there was an association between diabetes and the highest wealth quintile in LICs and the two highest wealth quintiles in LMIs but no association between household wealth and diabetes in UMIs.

CONCLUSIONS

In this study of 588,574 individual participants from 29 LMICs, we found an overall prevalence of diabetes of 7.5% among adults 25 years old and older, of which more than half was undiagnosed. In this group of countries, prevalence estimates of diabetes and the subset with undiagnosed diabetes increased with increasing WBIG. The relationship between

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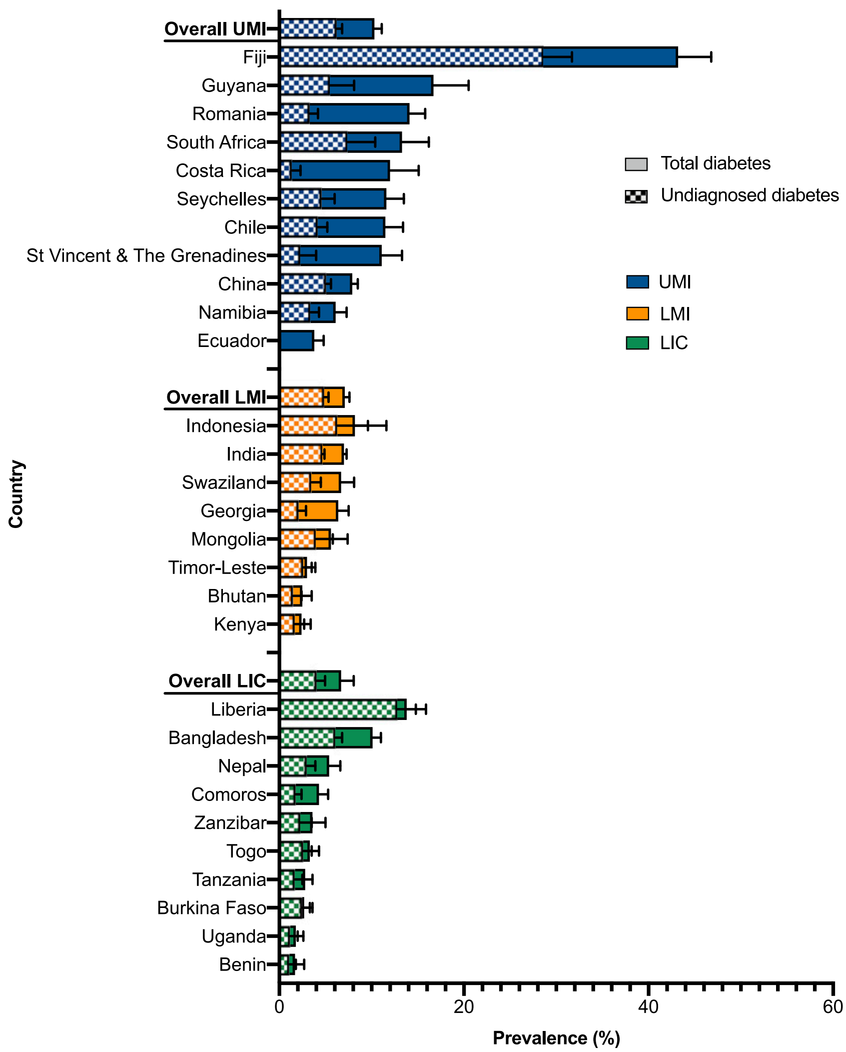

Figure 1—Country-level prevalence of total diabetes and the subset with undiagnosed diabetes in 29 population-based surveys conducted between 2008 and 2016, by World Bank income classification. Country classification at time of survey according to World Bank gross national income per capita in USD (Atlas methodology). Prevalence accounts for complex survey sampling design. Values are not adjusted for age and sex. Overall prevalence estimated with sampling weights scaled such that each country contributed proportionally to its population size. Unable to estimate undiagnosed diabetes prevalence for Ecuador, given no information available on diabetes diagnosis self-report in the Ecuador ENSANUT 2012 survey.

educational attainment and diabetes was also preserved at the individual level, where we found that diabetes risk was highest among those with higher educational attainment compared with no formal education across WBIGs. This association remained statistically significant even after adjustment for BMI, with an estimated increase in the risk of diabetes of 47% in LICs, 14% in LMIs, and 28% in UMIs for participants with secondary school or above compared with no formal education. The relationship between household wealth and diabetes was weaker than that observed with educational attainment and was most pronounced among those in the highest wealth quintiles in LICs and LMIs only.

Our findings expand upon earlier studies (29,30) by examining individual-level prevalence of diabetes and undiagnosed diabetes across three WBIGs and highlight several important aspects of diabetes prevalence in low-resource settings. First, the prevalence of diabetes and undiagnosed diabetes in the LMICs included in this analysis is substantial and seems to increase with national income, consistent with International Diabetes Federation estimates of diabetes prevalence being higher in middle-income compared with low-income countries (29). As extensively documented in prior studies on the global obesity epidemic (17,28), the trends observed in our analysis may be largely explained by the concomitant rise in BMI in LMICs, which may be of particular concern in Latin America and the Caribbean, Southeast Asia and Pacific, and the Middle East and Central Asia, where diabetes prevalence among participants with obesity ranged between 14.4% and 20.0%. This is consistent with prior studies showing an upward shift in BMI among those who are overweight and obese in LMICs (31). Secondly, undiagnosed diabetes comprised more than half of the total diabetes prevalence across WBIGs and in two of the four geographic regions included in this analysis. Given that unmet need for diabetes care in LMICs is high (17) and that regardless of national income level glycemic control is thought to be achieved by <25% of patients with diabetes in LMICs (19), these findings highlight the importance of screening efforts to ensure timely detection of diabetes and linkage to care for diabetes in LMICs.

The finding that greater educational attainment and, to a lesser degree, greater household wealth are associated with higher diabetes risk across WBIGs has several important implications that can be contextualized in the nutrition and obesity transition frameworks (16–18). Five stages of the nutrition transition have been proposed that together encompass economic, demographic, and epidemiologic changes associated with large shifts in dietary and physical activity patterns in LMICs. Broadly, the stages progress from hunter-gatherer lean phenotypes (stage 1) to industrialized societies with low levels of physical activity and high consumption of energy-dense foods, resulting in the rise of obesity and diabetes (stage 4). The fifth stage is posited to occur in countries with higher economic growth such as the U.S., where individual-level behavioral change, adopted initially by groups of higher SES, may lead to intentional reductions in sedentary behavior and the introduction of healthier eating habits (18). In our study, the relatively high prevalence of diabetes and the positive association between greater educational attainment and diabetes risk suggests that the countries included in our analysis may be at an advanced stage in the nutrition

Table 3—Multivariable Poisson regression analyses of the relationship of total diabetes with educational attainment and BMI, overall and by World Bank income classification

Model (variable adjusted for)	Overall (*N* = 562,445)	*P*	LIC (*N* = 26,629)	*P*	LMI (*N* = 510,377)	*P*	UMI (*N* = 25,439)	*P*
Model 1								
No formal education	Ref.		Ref.		Ref.		Ref.	
Primary school	1.30 (1.15–1.46)	<0.001	1.53 (1.29–1.82)	<0.001	1.29 (1.18–1.41)	<0.001	1.21 (0.96–1.52)	0.107
≥Secondary education	1.58 (1.43–1.75)	<0.001	2.15 (1.77–2.61)	<0.001	1.65 (1.54–1.77)	<0.001	1.42 (1.12–1.79)	0.003
Model 2								
No formal education	Ref.		Ref.		Ref.		Ref.	
Primary school	1.24 (1.10–1.40)	<0.001	1.44 (1.21–1.71)	<0.001	1.16 (1.07–1.27)	<0.001	1.20 (0.95–1.51)	0.119
≥Secondary education	1.36 (1.22–1.52)	<0.001	1.66 (1.37–2.02)	<0.001	1.24 (1.15–1.34)	<0.001	1.34 (1.07–1.69)	0.012
Model 3								
No formal education	Ref.		Ref.		Ref.		Ref.	
Primary school	1.17 (1.04–1.31)	0.009	1.36 (1.15–1.62)	<0.001	1.10 (1.01–1.20)	0.025	1.17 (0.93–1.46)	0.177
≥Secondary education	1.24 (1.11–1.38)	<0.001	1.47 (1.22–1.78)	<0.001	1.14 (1.06–1.23)	0.001	1.28 (1.02–1.61)	0.033
Model 4								
Underweight BMI	0.65 (0.57–0.75)	<0.001	0.70 (0.58–0.85)	<0.001	0.71 (0.64–0.79)	<0.001	0.56 (0.35–0.89)	0.015
Normal weight BMI	Ref.		Ref.		Ref.		Ref.	
Overweight BMI	1.89 (1.71–2.07)	<0.001	1.70 (1.43–2.02)	<0.001	1.80 (1.68–1.92)	<0.001	1.95 (1.54–2.14)	<0.001
Obese BMI	2.89 (2.56–3.26)	<0.001	1.54 (1.24–1.91)	<0.001	2.64 (2.37–2.95)	<0.001	3.45 (2.77–4.30)	<0.001

Data are RR (95% CI). Model 1 was adjusted for age and sex. Model 2 was adjusted for age, sex, and wealth. Model 3 was adjusted for age, sex, wealth, and BMI. Model 4 was adjusted for age, sex, education, and wealth. SEs were adjusted for clustering at the primary sampling unit level, and each country was weighted proportionate to its population size. Burkina Faso, Chile, Costa Rica, and Fiji were dropped from multivariable prediction models due to a lack of data on household wealth quintile. Seychelles was also excluded, since a harmonized wealth quintile was not available at the time of this analysis. Multivariable Poisson regression for the relationship between total diabetes and wealth quintile is provided in Supplementary Data.

transition (stage 4) but with little evidence of reversal in the socioeconomic gradient of diabetes risk (stage 5). This model would predict that as LMICs continue to develop economically, the burden of diabetes may shift to mirror that of high-income countries, with higher diabetes prevalence in groups with lower educational attainment (32).

Consistent with prior studies, we also found that while overweight and obesity are major drivers of the growing diabetes epidemic, the relationship between educational attainment and diabetes risk was not solely attributable to higher BMI (14,33). Additional factors that may mediate this relationship include poor diet quality and physical inactivity, an independent risk factor for type 2 diabetes (34) that may be more prevalent among higher SES groups in LMICs (35). Moreover, we found that the relationship between diabetes risk and educational attainment was more robust and consistent across WBIGs than the results observed with household wealth as the SES variable of interest. Compared with household wealth and occupational grade, education is often regarded as a more stable marker of SES, since it incorporates elements from the childhood social environment (33,36). Studies have also suggested that education may be a more sensitive marker of SES for the development of incident impaired glucose tolerance and type 2 diabetes (33). In contrast, measurement of income at the household level in LMICs may be more difficult to assess, given greater reliance on the informal economy, self-employment, and seasonal activity (37).

There are several limitations to this study. First, the definition of biochemical diabetes was limited to a single glucose measurement in some countries and, most importantly, was based on capillary measurement in many studies. Using capillary readings can over- or underestimate the true prevalence of diabetes even when readings are adjusted to device-specific plasma equivalents (38). Additionally, heterogeneity in survey methods such as the age of inclusion, use of different biochemical measures of diabetes, and challenges related to assay calibration may increase the variability in prevalence estimates across surveys and published estimates (39). Overall, these limitations highlight the challenges of standardization of glycemic measures in population-level surveys. Further research and clear guidance are needed to address these important shortcomings, particularly in low-resource settings, where the burden of diabetes is growing along with efforts to track its prevalence and impact.

Secondly, we included data from 29 LMICs, and trends in prevalence and socioeconomic level characteristics associated with diabetes may not apply to LMICs not represented in this sample.

Another consideration is that while we discuss our findings in the context of the nutrition and epidemiologic transitions occurring in developing countries, the cross-sectional design of our analysis represents only a snapshot of where countries may be along the nutrition transition at a single time point. Additionally, these surveys were conducted in different years, ranging from 2008 to 2016, and it is possible that some of the observed differences between countries were due to period effects rather than different stages of economic development. Thirdly, the available data on diabetes do not distinguish between different types of diabetes. However, type 1 and other types of diabetes likely represent <5% of the overall population of adults affected by diabetes, such that the associations observed are most relevant to type 2 diabetes. Additionally, data on urban versus rural status as well as race and ethnicity were not included in this analysis, given absence of these variables in the majority of surveys. Finally, adjustment for body adiposity in multivariable models, admittedly the single strongest predictor of diabetes in most populations, was limited to BMI, which only partially reflects a person's adiposity (40).

As LMICs undergo the epidemiologic transition with increasing prevalence of noncommunicable diseases, there is an urgent need for research to better characterize the burden of these conditions in lower-resource settings. We found that the prevalence of diabetes, most of which is undiagnosed, is substantial in the LMICs included in our analysis and rises with national income. Additionally, we found that educational attainment was strongly associated with diabetes risk across all WBIGs and that this relationship was partly but not solely mediated by BMI. While these countries may be at an advanced stage in the nutrition transition, reflected by a relatively high diabetes prevalence, we observed no evidence of a reversal in the socioeconomic gradient of diabetes risk. Our findings can help inform policies to target populations at risk for diabetes and to better understand the socioeconomic gradient and its relationship with diabetes risk in lower-resource settings. Given the numerous limitations and cross-sectional design of our analysis, future studies are urgently needed to characterize the growing burden of diabetes in LMICs.

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